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MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. CXI.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

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CORRIGENDA.

Vol. cx. p. 49, line 8 from bottom, *after* "A" *insert* "shows a."
„ 52, „ 14, *for* "earth" *read* "world."
„ 305, „ 3, *for* "western" *read* "eastern."
„ 306, „ 13 from bottom, *for* "easterly" *read* "westerly."
„ 308, „ 23, *for* "18" *read* "9."
„ 309, „ 7 from bottom, *for* "6" *read* "16."
„ 310, „ 14 from bottom, *dele* "but."
„ 311, „ 17 from bottom, *for* "favourably" *read* "unfavourably."
„ 322, „ 5, *for* "3*s.* 5½*d.*" *read* "2*s.* 11*d.*"
„ 404, „ 14, *for* "carbonic oxide," *read* "carbonic acid."
„ 451, „ 22, *for* "fine," *read* "form."
„ 455, „ 8 from bottom, *for* "sulphuric" *read* "sulphurous."

THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1892-93.—PART I.

Sect. I.—MINUTES OF PROCEEDINGS.

8 November, 1892.

HARRISON HAYTER, President,
in the Chair.

Gentlemen,—

On the occasion of a new President first meeting his professional brethren at the commencement of a session it is understood that the initial step should be taken by him, and that he should address the meeting. In the performance of this duty my predecessors have, with one or two exceptions, chosen as their topic branches of engineering which for the most part they had themselves taken up as a speciality, or have given an account of the more prominent works recently executed or in process of execution at the time they held office.

One departure from the general precedent was the address of Sir George B. Bruce, who, being President in 1887—the Jubilee year of Her Most Gracious Majesty Queen Victoria—naturally chose for his subject the progress of engineering during the previous 50 years. I also propose a departure, and purpose to deal not with past achievements but with future prospects, a subject that must interest all engineers who desire the advancement of the human race, and are hoping to have some share in its accomplishment. The subject in its entirety is too large to be dealt with in an address that is supposed to occupy not much more than an hour, so I propose to notice only, or at any rate chiefly, such works of importance as are likely in the not distant future to be undertaken by British Engineers both at home and abroad, and the principal fields of future employment.

If we regard our own country, it may seem to many that we have almost reached finality in respect of the creation of new undertakings of importance, and that little remains to be done by the engineer but to enlarge, improve, and uphold works already constructed. But the bare fact of works having been called into existence necessitates

other works, and when consolidated into systems, undertakings, and the corporate bodies to which they belong, assume great wealth and importance. This enables them to raise money on such easy terms that it becomes possible and worth while, in order to perfect a system, to construct works which appeared at the outset to have been out of the question from their magnitude, and prohibitive on account of cost. Hence we have at home the Forth and Tay Bridges and the Severn and Mersey Tunnels, and on the continent the Mont Cenis and the St. Gothard Tunnels uniting two countries, the Arlberg Tunnel uniting two Austrian provinces, and under construction the large bridge at Tchernavoda uniting the Roumanian railways on either side of the Danube.

But there are still works to be constructed to fill up gaps to further perfect railway systems even in the United Kingdom, or to connect them with other systems, in the execution of which the British Engineer will be engaged.

Tunnel between England and France.

The most prominent of these is to place England in unbroken railway connection with the continent of Europe by a tunnel under the English Channel. My late partner, Sir John Hawkshaw, had been studying this great question for some thirty years, and later on, his son, Mr. Hawkshaw, M. Inst. C.E., and I, were associated with him in the enquiry, as well as the late Sir James Brunlees and Mr. McKerrow. Not every one is acquainted with the extent, nature, and value of the investigations that have been made. The sub-marine route we proposed leaves the English coast between Dover and St. Margaret's Bay at a spot about four miles north-eastward of Dover, and proceeds in a straight line to the French coast near Sangatte, some 6 miles south-westward of Calais.

The desirability of this route was determined by borings taken both on the English and French coasts, and by soundings and investigations made by Mr. H. M. Brunel, M. Inst. C.E., to ascertain the outcrop of the strata, and also by geological investigations previously undertaken by Mr. Hartsinck Day, an experienced geologist. The general accuracy of the conclusions has been confirmed by further elaborate investigations subsequently made by French engineers and scientists, including the late Lavalley, M. Inst. C.E., and there is no doubt that whilst no line could be selected which, for physical reasons, would be better, it would in a very complete way serve the interests of the railways on either side. The tunnel would penetrate the lower chalk

throughout, and there would be no "faults" materially to affect the continuity of the strata. It is well known also that from its plastic nature little or no water is encountered in the lower beds of the chalk, whilst much is met with in the upper beds. The total length of the railway would be about 35 miles, of which about 21 miles would be in a sub-marine tunnel, the remainder being the approaches and connections on either side. The maximum depth of water in the Channel is 180 feet, and the depth from the bed of the sea to the level of the rails would not be less than 200 feet. The Channel Tunnel Company is exploiting a tunnel on a different line, the physical characteristics and the strata to be penetrated being, however, generally similar. But the first question to be settled is the political one, in respect of which there will be, of course, differences of opinion; but if permission to proceed be conceded, the enquiry as to the best route would then without doubt receive the consideration it deserves before a competent tribunal.

The question of constructing a bridge between England and France, instead of or in addition to a tunnel, may for the present be dismissed. Even in these times, and after we have become accustomed to magnificent works, the project is too vast a one as yet to be entertained. The possibility, however, of the realization in the more or less distant future, of such a structure is probably not more visionary than would have been that of such a work as the Forth Bridge fifty years ago. And who knows whether a future generation may not undertake a work which the present generation would regard as too gigantic both as regards risk and cost. Especially I may emphasize "cost," for, notwithstanding the strides made in bridge-building, the cost of a channel bridge between England and France would even now probably be at least five times the cost of a sub-marine tunnel.

Tunnel between Scotland and Ireland.

Another great tunnel work which has already received considerable attention, and which is likely to receive more, is one to unite the English and Scotch railways with those of Ireland. The subject has recently been revived by Mr. James Barton, M. Inst. C.E., who asked Mr. Hawkshaw and myself to co-operate with him in studying the question.

Several routes crossing the north channel between Wigtownshire and the Irish coast have at different times been suggested, where (excepting at the Mull of Cantyre) the channel is the narrowest,

the distance from the Scotch coast to the Irish coast being within a mile or two the same as between the English and French coasts, where the tunnel between the two shores would, if constructed, be located. Some of the proposed routes, however, between Scotland and Ireland, would cross what is named in the Admiralty chart "Beaufort's Dyke," which is a ravine in the sea-bed running nearly parallel to the coast of Scotland, at a distance of about 6 miles from it. It is as much as 3 miles wide at places, and has a maximum depth of water of 900 feet. The project Mr. Barton and my firm laid before an influential meeting, held at Belfast in October 1890, and afterwards before a meeting at the Society of Arts in February 1891, when a Paper on the general question was read by Sir Roper Lethbridge, K.C.I.E., was a tunnel passing round the northern end of the Dyke, where there is a maximum depth of water of 500 feet. Further investigation might show the desirability of somewhat modifying this route, but the information derived at present seems to indicate that it possesses advantages, both as regards cost and facility of construction, over any other proposal. The geological features have been investigated by Professor Hull, F.R.S., lately head of the Geological Survey of Ireland, and he reports that the strata to be traversed on the Scotch side would be the Lower Silurian rocks, and on the Irish side the red marls which overlie the new red sandstone, which were penetrated also by the Severn tunnel. Mr. Topley, F.R.S., confirms Professor Hull's conclusions, and states that the Lower Silurian rocks would extend about one-third of the way, and the red marls and new red sandstone two-thirds of the way. The tunnel would be at such a depth as at no part to be nearer the bed of the sea than 150 feet.

A tunnel from the Mull of Cantyre to the North Antrim coast has been proposed by Mr. Macassey, M. Inst. C.E., in a pamphlet written by him, the project being put forward, no doubt, on account of the shorter distance from shore to shore. But such a line would be of no use for English traffic, as the land distance to be traversed to get to the Mull of Cantyre would preclude its adoption. Further, such a line, with its long new connecting railways, would scarcely cost less than other more direct routes which have been suggested.

General Conclusions as to the Two Tunnels.

The result of the investigations that have been made which are applicable to a tunnel between Scotland and Ireland, as well as to

a tunnel between England and France, warrants the following conclusions:—

Firstly, that there is every reasonable probability that the tunnels can be made, but it would be improper to say that their construction would be unattended with a certain amount of risk.

Secondly, that the risk would be limited to one contingency, viz., the possibility of sea-water finding its way, by some unforeseen fissure, into the workings in quantity too great to be overcome. Apart from this risk, the execution of a tunnel of the length of the two under consideration would be a question of time.

Thirdly, the question of risk would probably be solved by sinking the land shafts—which form part of the permanent work—on each coast, and by driving the permanent driftways. This portion of the work being safely accomplished, the remainder would be of an ordinary character.

Fourthly, the loss, if there be any, would thus be measured by, and limited to, the cost of the preliminary shafts, or, as an extreme case, by the cost of these shafts and driftways, but it is improbable that there would be any loss.

Fifthly, there seems to be no reason to assume that these tunnels would cost more than £10,000,000 each, or that they could not be completed each in ten years.

As regards the financial aspect of such great undertakings, the following are facts not generally understood in this connection:—

1. For exceptional works, Parliament allows exceptional rates to be charged. Thus the traffic passing over the section of the railway, 3 miles 7 furlongs in length, which includes the Forth Bridge, can be charged a 10-miles rate within certain neighbouring limits, and a 19-miles rate beyond these limits, and for the traffic through the Severn tunnel, which is $4\frac{3}{8}$ miles long, charges can be made as though it were 12 miles long. It is not unreasonable, therefore, to expect that a greatly increased mileage rate would be conceded in the case of such undertakings as the tunnels under consideration.

2. The whole tunnel and approaches would be traversed from end to end by the traffic, and the neighbouring lines would converge to the one through route concentrating traffic on it.

3. The expense of working would be relatively small. There would be no intermediate stations or junctions, so the run would be unbroken, and the wear and tear of rolling-stock reduced to a minimum. Further, the cost of maintenance would be small, for there would be no embankments to settle, and no atmospheric

influences injuriously to act on the tunnel railway. It is true there would be exceptional charges for ventilating and pumping; but, taking these into account and the experience derived from the Severn tunnel, it is probable the working expenses would be at least 10 per cent. less than the cost of working railways in this country with large traffic, or they would amount to 40 per cent., instead of, say, 50 per cent. of the gross receipts if ordinary rates only were charged; but if higher rates like those I have referred to were charged, as they would be, the profit would be proportionately enhanced.

I briefly allude to these points in order that those interested may have data to go upon to assist in arriving at possible commercial results. But such undertakings are not to be measured solely by the profit they would realize if regarded as independent isolated works. They must materially increase the traffic of the neighbouring lines, and more or less of other lines further removed, and they would add to national wealth.

Other Sub-Aqueous Tunnels.

Other sub-aqueous tunnels may be noticed which will probably be constructed in this country.

One is to connect the railways north and south of the Humber by a tunnel under that river, and to obtain for the southern lines a terminus at Hull, thereby doing away with the necessity of the present communication by the New Holland and Hull Ferry, a scheme in respect of which some action has already been taken.

A further sub-aqueous tunnel that has been the subject of consideration by different promoters, is one uniting the railways on either side of the Thames by a tunnel passing under the river at some point between Purfleet and Grays Thurrock, and an Act for one of the proposals crossing the Thames at Purfleet was obtained in 1876, the engineers being Messrs. Lawford and Haughton. The length of the tunnel would be about $1\frac{3}{4}$ mile.

Another sub-aqueous tunnel which has been contemplated has for its object to connect the railways in the Isle of Wight with the London and South Western Line, and so with all the English railways.

It is not improbable that these three sub-aqueous tunnels will be constructed before long. Tunnel construction has recently made great advances; improved rock drills, tunnel machinery, and nitro-glycerine and other explosives facilitate operations in rock, and the use of air-pressure enables tunnels to be constructed

in soft and water-bearing strata at shallow depths, whereby the cost of the tunnel and approaches is minimized.

As bearing also upon the construction of future sub-aqueous tunnels, and the likelihood of their successful accomplishment, I may mention the St. Clair Tunnel, on the Grand Trunk Railway of Canada, under the river St. Clair, at the foot of Lake Huron, completed and opened for traffic only a little more than a year ago. This tunnel is 6,026 feet long, and its interior diameter is 20 feet. It is in soft soil, and at a shallow depth under the river bed, and is lined throughout with cast-iron plates. It was constructed by means of heavy wrought-iron shields, 21 feet 6 inches diameter, which were pushed forward by twenty-four hydraulic rams, each exercising a force of 125 tons. The time occupied in constructing the tunnel was twelve months only, and the cost £145 per lineal yard. The successful carrying out of this important link is due to Mr. Joseph Hobson, M. Inst. C.E.

Inland Navigation.

Turning next to the future of canals and inland waterways in this country, much information has been collected in connection with this subject through the medium of a Conference on Canals and Inland Navigation, brought about at the instance of the Society of Arts, London, and held at their meeting-room on the 10th and 11th of May, 1888; also by the International Congress on Inland Navigation, held on the 28th of July, 1890, and following days, at Manchester, and presided over by Sir Michael Hicks-Beach, Bart., M.P., the then President of the Board of Trade. This Congress was the fourth of a series, the three previous ones having been held at Brussels in 1885, at Vienna in 1886, and at Frankfort-on-Main in 1888, while a fifth was held this year in Paris, under the patronage of President Carnot. The object of these Congresses has been to promote the improvement of inland navigation and of estuaries, to direct attention to the commercial value of navigable waterways, to examine technical questions relating to the construction and working of canals, and to collect statistics bearing on inland navigation.

It is owing, in a great measure, to the labours of the Conference at the Society of Arts, and the International Congresses referred to, that Inland Navigation is now receiving revived attention.

From Board of Trade returns, made in compliance with the provisions of section 39 of the Railway and Canal Traffic Act,

1888, it appears that there are 3,814 miles of inland navigation in the United Kingdom, of which 2,609 are controlled by eighty-nine different trusts or canal companies, and 1,205 miles are owned or leased by thirteen railway companies. About one-third, therefore, of the canals of the country belong to the railway companies, and this one-third, although for the most part through the busiest part of the country, carries only one-fourth of the total tonnage conveyed on canals, and, according to Sir Michael Hicks-Beach :—

"The gross receipts per mile on that one-third are considerably less than they are on the independent canals."

And he adds :—

"I confess, without desiring to say anything that should be unpleasant to the railway companies, that these facts do seem to me to give some colour to the accusation which has been frequently made, that when a railway company becomes the owner of a canal, it works that canal rather for the profit of the railway than for the profit of the canal or the advantage of the community."

But this is not all, for railway companies have in some cases blocked through communication and connections, and rendered navigations less useful, thereby stopping the competition that otherwise would exist between canals and railways. Canals have had to succumb in every way to their more powerful competitors, and although the railway companies are by Act of Parliament required to keep the canals acquired by them thoroughly repaired, and in good working order, yet they have been allowed to fall into decay, and owing to the languishing condition of the undertakings generally, modern appliances for better working the traffic cannot be taken advantage of.

There are some circumstances which lead to the hope that the canals of the country will be soon placed on a more satisfactory footing, and that this will lead to the construction of many more works for the improvement and extension of inland navigation. In times of trade depression especially, outcries are raised against the high rates charged by railways, rendered necessary, to a considerable extent, no doubt, by their great cost. Hence, manufacturers, producers, and the agricultural interests, are placed at a disadvantage and the country suffers. In France and in Belgium, on the other hand, where canals are not controlled by railway companies, but where there is unrestricted competition, they are in a most prosperous state and the consumer largely benefits.

The importance of canals to the community, and the relief which would be afforded by a perfected canal system in a fair field of action, may be judged from the following figures given in evidence

by Mr. F. R. Conder, M. Inst. C.E., before the select Parliamentary Committee in 1883 (Sir Thomas Salts' Committee on Canals).

Average cost per mile in England and Wales	Canals, £3,350. Railways, £46,000.
Cost of maintenance of works for equal volumes of traffic . . .	Canals less than one-fourth that of railways.
Cost of conveyance of heavy materials	Less than one-third of their conveyance by railway.
Economy of transport by canal .	64·7 on working expenditure.

And I may add that it often costs less to convey a ton of goods to India, China, South America, or Australia, by sea, than it does to convey the same ton of goods to Newcastle-on-Tyne, for instance, from London by railway.

These are striking facts, and foreign competition is now so keen and increasingly so, that they will be more readily realized. The unsatisfactory position of our canals has enabled France, Belgium, and Holland, to carry coal or heavy goods so cheaply as to handicap us in foreign competition. The state of things is so serious for the country, that the more the facts are recognized the more probable it is that relief will be obtained. The question affects the interests of the engineer as well as the politician, and it is right to draw attention to it on an occasion like this, considering it is almost the only one which can be taken advantage of by us as a body to consider such questions in this manner.

It is only comparatively recently that Parliament has to any appreciable extent realized the true position of canals, and the gradual but crushing injury inflicted on the community by the existing state of these undertakings. This led to the passing of the Railway and Canal Traffic Act of 1888, an Act which, although probably insufficient to meet the case fully, appears to have had some effect of a beneficial character if we may judge from the many canal projects which have since been mooted.

Thus, Birmingham and the many towns in the neighbourhood, which allege as their reason the heavy railway charges, contemplate the construction of a canal from Birmingham—as the centre—to the Humber, using "en route" and improving the River Trent.

Then again, the Trent (Burton-upon-Trent and Humber) Navigation Company proposes to render the navigation of the Trent, and the Trent and Mersey Canal, more efficient, and thus obtain an improved water-communication between the sea and Burton-on-Trent. It also proposes to improve some tributary canals.

Another proposal is to make a canal to bring Birmingham and the neighbouring manufacturing districts in direct water-communication with Liverpool by a canal to join the River Weaver navigation at Winsford, which navigation joins the Manchester Ship Canal at a distance of about 11 miles from its commencement at Eastham. The promoters are confident that they could profitably carry goods at a cost not exceeding 5*s.* a ton between Birmingham and the ship at Liverpool, and they expect to realize a large profit.

Still another proposal has for its object to bring the manufacturing district having Birmingham for its centre in communication with the Bristol Channel. This is to be effected by widening and deepening the Birmingham and Worcester Canal, the stretch of the River Severn to Gloucester, and the canal from Gloucester to Sharpness on the Bristol Channel. Works are already in progress to effect this object.

There have also been proposals to widen and deepen the canals between Birmingham and London, to connect the Tyne and Solway by a canal and the Forth and Clyde by a direct ship-canal. Also to construct a canal for ships between the Bristol and English Channels, *viâ* Bridgwater and Lyme Regis, a project which is only the revival of an older one proposed by Telford in 1824, an Act for which was obtained in 1825. The construction of the canal was prevented by the financial disasters of that and succeeding years.

The above, excepting perhaps the two last mentioned, are not ship canals in any way of the type of the Manchester Ship Canal, but the proposals respecting them will probably constitute the type of the future canal. The depth of water is proposed to be from 9 to 12 feet, and they are to be of sufficient width to accommodate barges capable of carrying 400 tons, which is a not uncommon size of barge on some continental inland waterways. Thus, on the Francis Canal in Hungary, which I visited officially in 1875, the barges carry 400 tons and draw only 4 feet 6 inches of water. The depth of the new cuts of this canal are 6 feet 3 inches. It is intended to work the new projects in England by steam-power or by rope traction, and in some cases to introduce lifts instead of locks. In fact, the object contemplated is to make efficient waterways to be worked by modern appliances, to use larger craft, economizing time and cost of transport, and to bring the goods alongside the ships at the ports so that they can be transferred directly into them.

There is no doubt that the authorized construction of the Manchester Ship Canal was a factor in the revival of canal enter-

prise, leading to a desire to bring large manufacturing centres into direct communication with the shipping ports. It is unfortunate that the construction of this canal has been beset with such exceptional difficulties, and has in consequence cost such a large sum of money. This circumstance may retard the extension of canals, but I believe that within the next fifty years canal engineering and the improvement of rivers and tidal estuaries for navigation purposes will be a fruitful source of occupation for the British engineer, and if the undertakings become successful here the result will be the construction of canals and works of inland navigation in the Colonies and in foreign countries, carried out in many instances by British enterprise under British auspices.

Harbours.

A great deal yet remains to be done before our harbour accommodation is placed on a satisfactory footing. The casualties on or near the coasts of the United Kingdom, notwithstanding salutary legislation and voluntary benevolent efforts, are still very considerable.

Some fifty years ago Government had under consideration the construction of National Harbours of Refuge. The chief result was the creation of harbours at Holyhead, Portland, Dover, and Alderney. Of these Holyhead and Portland have been useful works for the purposes intended. Dover has never yet been carried out so as to enclose a sheltered area. A western arm alone has been built and serves chiefly as a pier for commercial purposes. It has just been handed over to the Dover Harbour Board, who, under the direction of Messrs. Coode and Matthews, MM. Inst. C.E., contemplate carrying out the idea of the original and subsequent designs, although on a restricted scale. Alderney, which, like Dover, was to be a harbour for strategic purposes as well as for shelter, has been abandoned after a sum of upwards of one million and a quarter had been spent upon it.

From the experience derived from these undertakings the plan to be followed in the future becomes clearer. Harbours of Refuge are chiefly useful to shelter small sailing-ships engaged in the coasting trade detained by contrary winds. Steamers are now largely replacing the small coasters, and, being independent of wind as the motive-power, do not seek shelter unless driven by undue stress of weather. Thus, taking Holyhead, the number of ships entering for refuge which attained a maximum yearly average of upwards of three thousand during the decade ending

1870, declined during the next decade ending 1880 to a yearly average of about two thousand five hundred, and during the decade ending 1890 there was a further decline to an average of about two thousand ships a year, at about which number it now remains. The harbours of Holyhead and Portland have nevertheless well repaid the outlay incurred in their construction, if against this is set the value of property saved; and have been besides the means of rescuing many lives. Their cost of maintenance is little more than a nominal sum. Necessary, therefore, as Holyhead and Portland always will be, especially in times of war and for national purposes, and useful as they still are and will be for refuge, such harbours are necessarily from their cost few in number and at great distances apart on the coast.

The true solution of the harbour question now, apart from that of national harbours, is to distribute them as much as possible along the coast and with such a depth of water that the usual coasting vessels may enter at all times. Thus, taking those which enter Holyhead Harbour as a gauge of the coasting shipping generally, there are a very few drawing more than from 10 to 12 feet water, and the majority are of lesser draught. For mere commercial purposes even a less depth of water than is required for refuge purposes is sufficient, as vessels with cargoes to discharge can wait, as they generally have to do even outside our largest ports, for the rise of the tide. Although, therefore, to make harbours available for refuge purposes, a greater depth of water may be necessary than for commercial purposes; yet, instead of constructing large and costly Harbours of Refuge, excepting for national purposes, Government might encourage the construction and improvement of smaller harbours by loans at the lowest current rate of interest, the stipulation being that the harbour shall be maintained at a minimum prescribed depth, and vessels entering for shelter only, without breaking bulk, should be allowed to do so at all times on the payment of a small toll only, which should be considerably less than that charged for vessels using the harbour for commercial purposes. The harbour in this way would not only become useful for refuge purposes, but also be materially improved for commercial purposes and the district would be benefited.

The harbour of Wicklow, in Ireland, recently constructed by Mr. Strype, M. Inst. C.E., at a cost of £40,000, a description of which he gave to the Institution in 1886, is typical of the kind of harbour I refer to, and in the construction of harbours of a like typical kind the French have been in advance of us. This has

been so at any rate on the Mediterranean littoral, especially along the whole of their coast eastward of Marseilles, where there is no place of any importance that has not a harbour with sufficient depth of water to accommodate coasting vessels and provided also with quay accommodation. Their distance apart does not average more than about 15 miles. It is true that the physical features are exceptionally favourable, for the numerous small bays or inlets along a great portion of this Mediterranean sea-board afford generally so much protection as to render only one breakwater necessary to enclose a sheltered area. Further the tidal range is insignificant, the shore in many places rocky where deep water is soon reached, and from the rocks suitable stone can be quarried for construction purposes.

Harbours constructed on the scale I have described would of course serve as deep-sea fishery harbours also. Much has been done in respect of this class of harbour in Scotland with beneficial results, but much more remains to be done. Still more has to be done in Ireland, where over a series of years, notwithstanding the expenditure of money, there has been but little useful progress to record. In 1886, a Royal Commission, consisting of the late Sir James Allport, Mr. James Abernethy, Past Pres. Inst. C.E., Mr. J. Wolfe Barry, M. Inst. C.E., and Mr. Joseph Todhunter Pim, was called upon to inquire—among other matters—

"To what extent the harbour accommodation on the coast of Ireland, either completed or in course of construction, meets the requirements of vessels suited for deep-sea fishing, and whether that industry can be promoted by the construction of new harbours."

The Commission advocated the construction of harbours, indicated the more important fishing-stations, and pointed out suitable sites. The report is exhaustive, and should lead to the construction of harbour works in Ireland which would be of untold benefit to that country.

Docks.

Dock enterprise has recently received a check from which it has not yet recovered. Thus, for instance, the East and West India Docks were a few years ago in a prosperous state, and their shares were at a high premium. At the present moment the company does not meet its debenture interest. The Hull Docks Company, which not long ago paid a substantial dividend, now earns nothing on its share capital, and its shares dropped from a high premium to a ruinous discount, and even its highest securities have been threatened. Disaster has in these and other cases arisen from com-

petition, and from unprofitable extensions forced sometimes upon corporate bodies to enable them to retain the trade they possessed, and sometimes, it is feared, from the nature of the administration. Thus it would not, for obvious reasons, seem to be consistent with sound policy that directors should be large freighters. The management should consist chiefly of those who are interested solely in the property of the docks themselves. A remedy is to place the docks under a Trust. Thus, taking Liverpool as an instance, so good has the security become that the trustees can raise money at 3 or $3\frac{1}{4}$ per cent. Owing to this sound financial position the trustees continue uninterruptedly to construct new works, and recently the dock system has been much enlarged under the direction of Mr. G. F. Lyster, M. Inst. C.E., as described by him in a Paper read before the Institution.[1] What effect the absorption of docks by railway companies will have yet remains to be proved, but there can be little doubt that if, as a general rule, docks were placed under properly constituted Trusts there would be hope for the undertakings which have suffered, and are still suffering, so severely, and a prospect of dock extension in this country on judicious lines.

Rivers.

The improvement of rivers for navigation comes under the head of "Inland Navigation," previously referred to, and the question of the pollution of rivers under that of "Sewerage of Towns," to be presently dealt with. But I notice now the question of Rivers in connection with land drainage and the prevention or mitigation of floods. I say mitigation, for agriculturists well know that floods of moderate extent and duration are not always prejudicial, but, on the contrary, have the effect of improving and fertilizing grass lands by the deposit which they bring down. The injury is when floods remain such a time on the land that the waters stagnate, which is bad for the land and injurious to health.

The present state of things connected with the Improvement and Legislation of Rivers is as follows:—

In 1877 a very influential Select Committee of the House of Lords was appointed, which was presided over by the Duke of Richmond. Its object was—

"To inquire into the operation of existing statutes in regard to the formation of and Proceedings by Commissioners of Sewers, and Conservancy, Drainage and River Navigation Boards. To consider by what means such bodies may be

[1] Minutes of Proceedings Inst. C.E., vol. c.

more conveniently and inexpensively constituted, their procedure improved, and their powers enlarged, so as to provide more efficiently for storage of water, the prevention of floods, and the discharge of other functions appertaining to such Boards."

The evidence taken showed that considerable damage had been caused in various parts by the prevalence of floods, and that such floods had been more frequent and of longer duration in recent times than formerly. Among the causes assigned for this state of things prominence was given to the general adoption of the system of subsoil drainage, owing to which a greatly augmented quantity of water is rapidly carried into rivers, and to the deterioration which is constantly taking place in the channels of rivers themselves, whereby they are rendered inadequate to carry off the drainage of their respective watersheds.

The Committee had under review the several Acts of Parliament which had been passed dealing with rivers, but came to the conclusion that they had "not worked successfully for the prevention of floods."

The Committee recommended—

"That in order to secure uniformity and completeness of action in dealing with each river, each catchment area should, as a general rule, be placed under a single body of Conservators who should be responsible for maintaining the river from its source to its outfall in an efficient state."

They made some exceptions in the case of tributary streams when under certain conditions.

And in order to facilitate the legislation necessary to give effect to their recommendation the Committee were of opinion that—

"A general statute in the nature of the statutes known as the 'Companies Clauses,' or 'Lands Clauses Consolidation Act' should be passed, embracing all the provisions applicable to this subject, and that so much of such general statute as is applicable to each particular case, should be incorporated with and form part of every 'Provisional Order' issued for the constitution of a conservancy district."

The Committee also reported very clearly as to "the principle of assessment which should be adopted in raising the rates which would be required to meet the expenses of conservancy."

Although the Duke of Richmond's Committee made most valuable suggestions, which to take effect must be incorporated in an Act of Parliament, nothing has as yet been accomplished, and complete schemes of river improvement cannot in consequence be undertaken.

To give an instance of the impossibility now of carrying out

drainage schemes, however anxious those concerned may be, I will give an illustration :—

In 1871 an Act was passed, empowering the Thames Valley Drainage Commissioners to execute works for the improvement of the district under their jurisdiction, which extends over the River Thames from its source at Thames Head to the southern boundary of the parish of Long Wittenham, about 18 miles below Oxford, and over the principal tributaries of that part of the Thames, draining altogether an area of 1,328 square miles. These tributaries included, amongst others, the Rivers Windrush, Evenlode, Cherwell, Ray, and Ock. The river channels in many places are too small, and from obstructions, such as shoals, trees, and weeds, having been allowed to accumulate in their beds, and from obstacles connected with the navigation and with mills, they are insufficient to carry off the rainfall of the district which they serve. Elaborate surveys, sections, and investigations were made, and in 1878, Sir John Hawkshaw reported as to the works which should be carried out, and laid down a scheme which would cost £216,000, which could be done in several sections, and allow of the expenditure being spread over several years. The works executed under the direction of my firm were commenced, but when the funds at immediate disposal were spent, the question arose how to provide more. There being no law to apportion the taxation to the several districts, and to lands situated at differing levels above the river, which, therefore, would be unequally benefited—and differences of opinion arising, rendered more diverse, perhaps, by agricultural depression—the works had to be suspended. The Thames Valley Drainage Commissioners, having obtained their Act, were justified in improving their own district; but whilst they did this, it is evident that their works would have had an injurious effect on the district of the Thames below Long Wittenham, by bringing down the upper waters upon it more rapidly. Nothing more clearly shows than this particular illustration the need of a general Act of Parliament to concentrate districts under one jurisdiction, and to regulate the incidence of taxation. It is hoped and believed, for it has often been agitated, and the necessity is obvious, that when the Government is relieved of the pressure of politics not of a domestic kind, a complete scheme embodying the recommendations of the Duke of Richmond's Committee —the materials therefor being ready at hand—will form part of our statute book. In the meanwhile, the country is suffering and patiently waiting. There is little doubt that if an Act of Parliament existed framed on sound principles, it would be a powerful

incentive enabling our long neglected rivers to be, by the intervention of the engineer, improved for drainage purposes.

Water-Supply of London and Large Towns.

Many of our large towns now obtain a supply of water of the purest kind from uncontaminated sources. Thus Liverpool is supplied from the upper waters of the River Vyrnwy in North Wales; Manchester is about to be from Lake Thirlmere in Cumberland; Glasgow is supplied from Loch Katrine; Dublin from the head waters of the Rivers Vartry and Dodder; and Birmingham is now about to obtain a supply from two of the upper tributaries of the River Wye. London, on the other hand, still obtains its water from sources for the most part within the range of contamination, rather more than one-half of the supply being obtained from the lower waters of the River Thames, and the remainder from the River Lea sources, and from deep wells.

There is no doubt that the problem of a better supply of water to London is beset with difficulties of no ordinary kind, due in a great measure to the power of the water companies and to their vested interests, which are large, and must of course be fairly dealt with.

Now, as we all know, a Royal Commission—on which are three of our members—is now sitting, their instructions being to report as follows:—

"Whether, taking into consideration the growth in the population of the metropolis and the districts within the limits of the Metropolitan Water Companies, and also the needs of the localities not supplied by any Metropolitan Company, but within the watersheds of the Thames and the Lea, the present sources of supply of these companies are adequate in quantity and quality, and if inadequate, whether such supply as may be required can be obtained within the watersheds referred to, having due regard to the claims of the districts outside the metropolis but within these watersheds, or will have to be obtained outside the watersheds of the Thames and the Lea."

As bearing upon the question of the "quantity" of water which it is assumed may be ultimately required, the London County Council, in a communication addressed to the Royal Commission, gave it as their opinion—

"That in dealing with the question of a new source or sources provision should be made for a population of at least twelve million five hundred thousand, and that in no case should the supply be for less than 35 gallons per person."

This, for 12,500,000 persons, will amount to 437,500,000 daily. Mr. Hassard, M. Inst. C.E., the originator of the scheme for

supplying Dublin with water from the Rivers Vartry and Dodder, and his partner Mr. Tyrrell, M. Inst. C.E., have investigated the question as to the possibility of obtaining for London such a large supply of suitable water from unobjectionable and available sources. They show that—

"Three hundred million gallons daily of the purest water can be obtained from the mountain districts of Brecknockshire and Radnorshire, in Mid-Wales unwatered by the rivers Usk and Wye, and be delivered at London, both on the north and south sides of the city, by gravitation at an altitude of 300 feet above Ordnance datum."

and this without interference with the district recently secured by the Corporation of Birmingham for the supply of that town.

This quantity of 300,000,000 gallons daily does not come up to the County Council requirement of 437,500,000 gallons. Indeed it is probable that no one source which could be suggested as reasonable could supply the required quantity for the most part by gravitation without being supplemented from other sources. Messrs. Hassard and Tyrrell propose to supplement the supply obtainable from their Mid-Wales project by available water from the wells of the New River and Kent Companies, and from springs in the Thames head district to be intercepted *en route*, from the chalk districts north of the Thames between Bourne and Reading, from the South Down springs near Havant and Woolmer Forest and Hindhead, and there are doubtless other sources available.

The County Council requirement as to quantity can thus be readily reached, large though it seems to be; for the 300,000,000 gallons from Mid-Wales is more than 50 per cent. in excess of the present consumption, and would certainly suffice for many years to come.[1] If it were to become necessary to increase this quantity hereafter, extensions like those referred to could be brought into use one by one as needed, and at an expenditure which would be comparatively small and could be graduated to the requirement of the time.

The Authors of this scheme deal also with certain economies which would be effected by the abolition of the present system of supply and by the introduction of pure soft water by gravitation,

[1] Mr. Hawksley, Past President Inst. C.E., the greatest authority on water supply, recently gave in evidence before the Royal Commission (1892) on Metropolitan Water Supply, that in the best managed towns the consumption of water never exceeds 25 gallons per head per day, and rarely goes beyond 20 gallons. Taking the higher allowance per head, a supply of 300,000,000 gallons daily would suffice for a population of 12,000,000, which is not very far short of the County Council's requirement.

and they estimate that the total diminution of annual expenditure and the probable increased income at the end of the year 1903 on the assumed introduction of the new supply might be taken at no less a sum than £1,500,000. The diminution of expenditure would arise from abolition, for the most part, of pumping, concentration of management, cessation of payments as royalties to Rivers Conservancy Boards, the value of the properties purchased, and many other smaller items. And the increased income would arise from the supply to new houses and for trading purposes. This sum of £1,500,000 capitalized at thirty-three and one-third years' purchase would represent an outlay of £50,000,000.

Of course such figures must be received with a considerable amount of reserve, and must be regarded as conjectural. But there is no doubt—and I allude to them for this purpose—that there are at any rate some economies which would result from the introduction of pure soft water delivered for the most part by gravitation, and that considerable sums of money might be laid out to obtain such a supply without, it is believed, any very undue ultimate additional taxation or cost to the consumer. This is assuming also that money can be borrowed by a responsible body —like, for instance, the London County Council—at 3 per cent. per annum.

As regards the "quality" of the London water as at present supplied, we know that everything has been done by Government, or is being done by careful and able official inspection, to ensure water being supplied of a purity as great as the existing conditions will admit. It is no doubt in a measure due to this inspection that the mortality of London is not only not abnormally high but is low, considering the surrounding conditions. But hygienic scientists, with more and more persistency, announce the fact that the water supplied to London, owing to impurities contained in it (more dangerous from being in solution), to disease germs which the chemist is powerless to detect, and to its hardness, is not conducive to the best health of the inhabitants.

Whatever, therefore, may be argued in favour of the present supply of water to London, there is no doubt a strong prejudice against it which it would be impossible to remove or even materially to mitigate. Hence it arises that, in addition to the filtration the water undergoes before delivery, almost every householder possesses his own private filter. Hence it is also that medical men, as a rule, recommend water to be boiled before it is used for potable purposes, and that there is a large trade in distilled water. Further, the fact must not be lost sight of that the Rivers Pollution

Commission of 1868 recommended (in 1874) that the Thames and the Lea should be abandoned as sources of water for domestic use.

The population on the margin of the rivers is great and continually increasing, and whatever care may be taken, the rivers must always be the recipients of a certain amount of sewage from towns, villages and houses, of liquid refuse from manufactories, and drainage from polluted lands. No laws that can be enacted, having for their object the prohibition to discharge offensive matter into such rivers, could do more than ameliorate the conditions to a greater or less extent; and they could not ensure that the water would at all times be fit for domestic use. And if the principle be established that London, like the other large towns I have enumerated, must seek for a pure supply of water outside the limits of its own watersheds, the desirability of this plan of procedure will be strengthened, and other towns of magnitude with an indifferent supply of water will be more likely to adopt the same principle, which must lead to the construction of waterworks both at home and abroad.

Sewerage (London and General).

The system of discharging sewage—especially in its crude state —into rivers is recognized on all hands to be an evil. The influential Royal Commission appointed in 1882 to inquire into the question of the "effects of the discharge of the sewage of the Metropolis into the River Thames"—and whose report is applicable to rivers generally under like conditions—enumerated the evils under five heads :—

1. Injury to the health of the neighbouring districts.
2. General nuisance and inconvenience from the pollution of the river.
3. Injury to fish.
4. The pollution of wells near the river.
5. The formation of shoals or banks which might prejudice the navigation.

To diminish injurious effects in the case of the London sewage, chemical treatment to purify the effluent is now being resorted to at the outfalls, and if the effluent could be discharged lower down the River, say at or near Hole Haven, the benefit would be great indeed. But it may be laid down, I think, as a rule, that the best plan to deal with sewage is to provide for its removal altogether by discharging it in its crude state into the

sea when this can be done, or, where it cannot, by distributing it over land favourably situated, whereby, if the soil be of a suitable character and its area large enough in proportion to the sewage distributed over it, the liquid filtered through and flowing off the land will be comparatively pure and inoffensive. The application however of this on a large scale, so as to render it free from objection, is often beset with great and insuperable difficulties.

Thus for many years the Maplin and the Foulness Sands, on the Essex coast, situated between the mouths of the Rivers Thames and Crouch, were regarded by some engineers as suitable places upon which to deposit the London sewage, at the same time reclaiming the flats and converting them into fertile lands, in order to do which extensive embankments, some in exposed situations, would have to be constructed. Such a proposal was in some favour when the sewage of London was much less in quantity than it is at present. But now that it has so much increased, and a still larger quantity has to be provided for, it is doubtful whether any such scheme could meet the present and prospective requirements, and it would be costly to bring into operation and to maintain.

It has also been proposed to discharge the sewage in its crude state direct into the sea at some point on this part of the Essex coast, but owing to the nature of the coast and the currents, and the existence of shallows, it is believed there would still be danger arising from polluted matter finding its way up the Thames and the adjacent rivers, and hence there would be no certainty that the contemplated remedy would sufficiently meet the case.

But Messrs. Hassard and Tyrrell have recently propounded a scheme for the removal of the London sewage in its crude state to the open sea at Dungeness Point, which is at a distance of about 56 miles from the present outfalls at Barking and Crossness —a locality very thinly populated.

"The nearest villages, Lydd and New Romney, being distant from Dungeness Point 4 and 5½ miles respectively, and for distances of about 3 miles inland, and of 5 and 7 miles coastwise from the Point in northerly and westerly directions, with the exception of the few people employed on coastguard service, at the railway, at the light-house, and at Lloyd's signal-station, the district is absolutely uninhabited."

It is a flat, desolate and uninviting tract of shingle, never likely to be inhabited more than at present, with water 90 feet deep and strong tidal currents immediately adjacent to the shore.

Messrs. Hassard and Tyrrell estimate the cost of the works necessary to discharge the whole of the London sewage into the

sea at Dungeness, allowing for a considerable increase in the population, at £5,750,000.

Now it has been estimated by a great authority that the cost of defœcating the London sewage by chemical treatment, and getting rid of the resultant sludge, might amount to £300,000 per annum, and the financial aspect of the question—assuming money can be borrowed at 3 per cent. per annum—would be as follows:—

	£.
Interest on £5,750,000 at 3 per cent. . . .	172,500
Cost of pumping and maintenance per annum .	50,000
Total	£222,500

Such estimates must of course only be regarded as very general and approximate. But it seems not unreasonable to suppose that the interest on the outlay that would be incurred in the construction of works to discharge the London sewage at a distant outfall like Dungeness, together with the cost of pumping and maintenance, might not be materially in excess at any rate of the cost of defœcation, unless that has been much over-estimated, and the cost of the works much under-estimated.

Of course if any sewage could be pumped up on its way to the sea and placed on the land so much the better. But there seems to be no disposition on the part of farmers to use it. The principle recommended by Messrs. Hassard and Tyrrell for London has already been adopted, on a smaller scale, by my firm in the case of Brighton, where the sewage is discharged into the sea at a distance of 4 miles from the extreme eastern end of the town, and although the chalk downs adjoining could be made into profitable agricultural land if irrigated with sewage, the occasion has not been taken advantage of. The level flats of the reclamation known as Romney Marsh adjoining Dungeness present an area eminently suitable for the profitable employment of sewage, to be had for nothing as far as the fertilizing agent is concerned, but necessitating of course an outlay for pumping and distribution.

Taking the pollution of the River Clyde as another case in point—in 1876 Sir John Hawkshaw, acting as sole Royal Commissioner, reported as to the causes which had led to the pollution of this river and its tributaries, and as to the best remedies for restoring them as far as may be to their original pure state. The polluted condition of the River Clyde and some of its tributaries is a nuisance to Glasgow and other towns and places, and to the traffic on the river. To remedy the evil, Sir John Hawkshaw

recommended the construction of intercepting sewers through the district, emptying into an outfall sewer discharging into the sea at Farland Point, situated midway between Largs and Ardrossan. The estimated cost of these sewers, including 15 per cent. for contingencies and interest on money during construction (an item too often eliminated from estimates), was £2,500,000. The interest at 4 per cent. per annum (it could now be raised at a lower rate), together with the annual cost of such pumping as would be necessary, and the cost of maintenance of the outfall sewer, was valued at £108,000, which sum is about 6½*d.* per £ on £4,000,000, the estimated probable amount of the rateable value of the property before the expenditure on the works would become a burden. It would, however, be impracticable to construct sewers communicating with the intercepting and outfall sewers referred to from all the outlying towns and villages, or from every work and manufactory, and these, very few in number, comparatively speaking, would have to be dealt with locally and by other methods.

The scheme laid down as the result of an exhaustive enquiry was most complete, and although it would not involve a heavy tax it still remains to be carried out. In order that this might be accomplished it was recommended that a Board of "Sanitary Commissioners of the Clyde" should be appointed, to consist of representatives (not to exceed thirty-six in number) of the various town councils or sanitary authorities within the area to be dealt with, and that they should have jurisdiction over the whole region draining into the Clyde, and be armed with authority to prevent the pollution of the waters.

London and Glasgow are merely given as instances of large centres of population, capable, it is believed, of discharging their sewage into the sea. I have shown that, as regards London, it might not ultimately tax the ratepayer much more, at any rate, than if the sewage were defœcated, and in Glasgow the project I have referred to would involve a tax of 6½*d.* on the rateable value. At Brighton the expenditure involved a tax of 3*d.* in the £, but this is now reduced to a fraction over 2*d.* in the £, owing to the increase in the rateable value of property in the district.

Much, very much, has to be accomplished before the main drainage of towns can be placed in a satisfactory state. And, as regards houses and dwellings, it is probable that not one can be pronounced sanitarily safe which has not been drained or remodelled as regards the drainage within the last fifteen years or so. Before that time pipe drains were laid by un-

skilled workmen, who, if they stopped the joints at all, did so by dabbing on a piece of clay, and everywhere they are known to leak. The modern system, following the by-laws of the Local Government Board, of having the channels of tested earthenware pipes laid with joints effectually stopped; of having through ventilation by pipes carried above the top of the houses; of disconnecting the rain-water, bath, and other pipes, and of using traps and gullies of improved design, and observing other details, leaves little to be desired. The subject of the sewage of large cities and towns, not neglecting the more humble one of houses and buildings, is one that may well be taken up by the engineer as a sole speciality to which to devote all his time and energies. The question has become a large one, and is of growing importance, opening out to the engineer an extensive field for present and future usefulness. But I venture to say that no one now should begin to take up this branch of our profession without possessing a knowledge of chemistry—a necessary acquisition to the efficient performance of his duties.

Hitherto I have dealt with home engineering. I will now notice some works abroad which the British engineer will probably be called upon to undertake.

Euphrates Valley Railway route to India (Plate 1).

One, if not the greatest, engineering question of the day is the expediency, and, as I hope to show, the necessity of taking immediate action if a Euphrates Valley route to India is to be established under British control. Much has been spoken and written on this subject, and so essential is the question to British interests that it demands especially at the present moment a more than passing notice.

The most energetic advocate of the Euphrates Valley line through Turkish territory was the late Sir W. P. Andrew. He initiated the inquiry as long ago as 1857, and never lost an opportunity by pen and voice to urge its importance.

In 1872 a Select Committee of the House of Commons was appointed to "examine and report upon the whole subject of railway communication between the Mediterranean and the Black Sea and the Persian Gulf." The Committee was an influential

one, the late Lord Iddesleigh (then Sir Stafford Northcote) being the Chairman. A great deal of evidence was taken, various routes were discussed, and the importance of the communication was demonstrated. But the Committee decided that there was no probability of the line being constructed by unassisted private enterprise, and they then considered the question as to whether it was (using the words of the report), " worth the while of England to undertake the making of the line in conjunction with Turkey."

In respect of this there was a difference of opinion, and the report of the Select Committee closed without any decisive recommendation. Facts, however, were collected, and information procured, and the report, and the evidence upon which it was based, are still of great value, and indeed essential to those who wish to pursue the inquiry.

It is now, however, quite evident that if the success of an undertaking is to be at all dependent upon any subsidy or guarantee from Turkey, the case would be hopeless. All that Turkey could do would be to grant a concession, but it must be one that would not unduly fetter the hands of the promoters, and which would concede privileges.

The question has now become almost dormant in this country, but it should be so no longer, for there is a danger that the work which should be undertaken by England as a political necessity may be, and in fact is now partly being, accomplished, or at any rate in imminent danger of being so, by others, and a note of warning may not be inappropriate, and engineers as well as capitalists may well join in the cry.

Thus a concession was (in 1888) granted by the Ottoman Government for certain railways in Asia Minor. The firman granted facilities for the acquisition of land, and hypothecated revenues of the district through the country the lines would traverse. The matter was brought before English capitalists, and in order to establish the terms of the concession, Mr. C. E. Austin, M. Inst. C.E., went out to Constantinople on the recommendation of my firm (who were to be the engineers to carry out the work), and Messrs. S. Pearson and Son entered into a provisional contract to construct the lines for the estimate. A German element, however, had to be introduced, and the end of it was that the German capitalists supplanted the British capitalists altogether, and the lines are now in their hands.

The first section of the lines commences at Ismid, and extends to Angora, a distance of about 300 miles. This is now under construction, and partly opened. The intention is, it is believed,

to prolong the line to Sivas and Diarbekir, and probably to Mosul on the Tigris. A legitimate extension would be to continue it down the Tigris Valley, and at some future time to Kurrachee in India, skirting the margin of the Persian Gulf and the Arabian Sea. There is at present a line from Ismid to Haidar Pasha, a place nearly opposite Constantinople, about 60 miles in length, and this the German company has acquired from the Turkish Government, to whom it belonged; so the lines would afford a communication from England through Europe to India, the only missing links in the communication between London and India being the English Channel and the Bosphorus. Already plans have been discussed for bridging or tunnelling the latter, which, although works of magnitude, are said to be quite practicable.

Now if a railway is to be made down the Euphrates Valley, or down the Tigris Valley, from opposite Constantinople, the legitimate route to take would be to traverse the same country as the first portion of the German line. Also it would be blocked at the other end if the German line were extended along the Persian Gulf in the direction of Kurrachee. The hope, therefore, is almost gone, that we, as a nation at any rate, can obtain the best railway communication between England and India, *viâ* Constantinople to Kurrachee down the Euphrates Valley, or down the Tigris Valley, without encountering in Asia Minor and perhaps eastward a length or lengths of railway belonging to a strong European power. The difficulty may eventually become a worse one than was that of the Suez Canal, which was the source of so much anxiety to merchants and capitalists, and the country generally, but out of which we were in a great measure delivered by the late Lord Beaconsfield, when, as Prime Minister, he induced Parliament to consent to the purchase from the then Khedive of Egypt of stock of the Canal amounting to £4,000,000, thus giving the country a voice in the control and management of the undertaking.

However, it is a matter of congratulation that the way is, for the present, still open, if we regard the Euphrates Valley line as a link in the communication from a Mediterranean Port on the Syrian coast to the Persian Gulf, which Sir W. P. Andrew and others have always regarded as of primary importance. The most likely routes that have been considered are the following:—

1. A line from Alexandretta (Scanderoon), or from Suedia (Seleucia), near the mouth of the Orontes River, passing through Aleppo to the Euphrates, at or near Jâber Castle, and thence carried down the right bank of the river to Grane (Koweyt), on the western side of the Persian Gulf.

2. A line starting from Tripoli and proceeding across the desert by way of Damascus and Palmyra to the Euphrates, and down the right bank of the river.

The Committee of the House of Commons of 1872 was disposed to prefer Alexandretta as the Mediterranean Port, as it possesses a fine natural harbour. The advantages of the Mediterranean Ports are that they are opposite Cyprus. Grane seemed to have had the preference as the Port on the Persian Gulf, yet Bussorah has its advocates. Should, however, the line be afterwards carried to Kurrachee, it would probably be better to keep on the left bank of the Euphrates, and to select Bushire as the port on the Persian Gulf. These questions might readily be settled by the usual preliminary investigations undertaken by engineers, but whichever of these lines be followed the route to India will be shortened. Thus the shortest route to India is now *viâ* Brindisi, the Suez Canal, and down the Red Sea to Aden, and so to Bombay or Kurrachee. By the Euphrates Valley route and along the Persian Gulf the saving to Bombay would be upwards of 700 miles, and to Kurrachee upwards of 1,000 miles.

The length of the Euphrates Valley line from the Mediterranean Port to the Persian Gulf would be about 850 miles, and the cost £8,500,000, or £10,000 a mile average, taking the length and estimate given by the late Sir John Macneil, M. Inst. C.E. The railways being constructed by the Germans in Asia Minor were estimated by my firm, and were provisionally tendered for by Messrs. S. Pearson and Co., as far as Angora, at the rate of £8,000 a mile, so that £10,000 a mile for the Euphrates Valley line, where there appears to be no engineering difficulties, and where the conditions would not be very dissimilar from the Angora line, would seem to be not unreasonable. Sir W. P. Andrew devoted considerable attention to arrive at the probable traffic on the Euphrates Valley Railway, and he estimated that the net revenue would pay a dividend of 5 per cent. per annum on a capital of £8,500,000. Mr. J. B. Fell also collected traffic statistics, and the opinion formed by him was that a larger dividend than 5 per cent. was probable on a capital of £9,000,000.

And with reference to the necessity of the line from a strategical point of view, I may say that Lord Wolseley, speaking at a meeting at the Royal United Service Institution, gave it as his opinion that the Suez Canal might be quickly and easily destroyed, and remarked that "as a nation it would be perfectly ridiculous for us to depend on the Suez Canal as a line of communication with our Eastern possessions in time of war."

If a line were made down the Euphrates, it is probable that another down the Tigris would soon follow, if others do not anticipate us in securing the territory. Apart from affording the long-desired and more direct route to India than the present one, the countries between the rivers, and on either side of them, are the most interesting in the world. Here is the cradle of the human race and of engineering, and the seat of Babylon, the capital of the Chaldean Empire. Ages of misrule and oppression have brought the country to its present unhappy state, but it is well known that if properly cultivated there is no more fertile spot in the world. This is what Herodotus said, and he added: "The earth is suitable for all sorts of grain, of which it yields 200 per cent., and, in years of extraordinary fertility, 300 per cent." There are vast sources of wealth in these Mesopotamian regions, only requiring railways, with reasonable concession facilities to open them out, benefiting our country, and giving employment to the engineer. Shall we, as a nation, let other powers take commercial possession of the country, and again have another route to India blocked? It is a question fraught with consequences of the greatest moment to the United Kingdom.

Euphrates Valley Navigation.

But there is another matter to be considered, rendering the engineering possession of the territory still more a necessity to our country.

In 1855 Captain Allen, R.N., published a work entitled, "The Dead Sea a new Route to India," with the view of establishing an alternative water route to India, which would entirely, and not, like the Suez Canal, in a secondary sense only, be in British hands. It was proposed to cut a canal from the Bay of Acre, on the Mediterranean, to the River Jordan, which would join it some little distance south of the Lake of Galilee, from which point the Jordan Valley runs nearly south to the Dead Sea. South of the Dead Sea another canal would be cut to the Gulf of Akabah, at the upper end of the Red Sea. Now the Lake of Galilee is 700 feet, and the Dead Sea 1,300 feet, below the level of the Mediterranean and the Red Sea, and a vast inland lake would be formed, some 140 miles long and 10 miles wide. The proposal was of too astounding a character to be entertained, and, apart from its physical difficulties, the sentiment of Christendom would have made itself conclusively felt against an enterprise which would for ever efface some of the chief scenes of our Lord's work on earth.

Following on this, however, and having in view the impracticability of this route, the late Mr. Thomas Andrew Walker, the well-known contractor, asked my firm to investigate a matter he had been considering, and that was the creation of a navigation from the Mediterranean, opposite Cyprus, to the Persian Gulf, the possible route being up the River Orontes, which embouches into the Mediterranean near Suedia, opposite Cyprus, and down the Euphrates to a port on the Persian Gulf.

My partner, Mr. Hawkshaw, took up the subject with much interest, and had access to General Chesney's surveys. These are useful as far as they go, but they are not sufficient in extent to enable it to be said whether such through water communication would, for physical reasons, be practicable; or, if practicable physically, whether the cost of establishing it might not be prohibitive. At present the Euphrates is navigable for small steamers as far as Balis some 800 miles—disregarding the sinuosities of the river—from the Persian Gulf, and the steamers of the Euphrates and Tigris Steam Navigation Company carry on a trade between the Persian Gulf and Balis and the Mediterranean. Mr. T. K. Lynch, the managing director of that company, advocated the construction of a railway from Balis, *viâ* Aleppo and Antioch, down the Orontes Valley to Suedia on the Mediterranean, the length of which would be 140 miles.

Looking at the whole question in a practical light, there is no doubt—and this will more directly interest us as engineers—that for every reason the first work to be undertaken in this region is the construction of the railway from the Mediterranean *viâ* the Euphrates Valley to the Persian Gulf. This is necessary and urgent if we are to have this route to India in our own hands. The Germans, if they continue their line beyond Angora, as far, for instance, as Diabekir, will cross both the Euphrates and the Tigris; it would be easy for them to make a railway down both these valleys, and they would be tempting extensions. It is not pleasant to anticipate such a state of things, and I trust it may not arise. If we succeeded in constructing a railway down the Euphrates Valley, it would then become a proper and interesting inquiry to ascertain to what extent, in order further to develop the country, a water, or partly water and partly railway, communication, could be established between the Mediterranean, opposite Cyprus and the Persian Gulf, down the Euphrates or Tigris Valley, or down both.

Many believe that the splendid country of Mesopotamia and the surrounding territory is destined again to recover its ancient

greatness, and that Babylon on the Euphrates—the site of which is now occupied by Hillah, a town of some ten thousand inhabitants, and is some 300 miles in a direct line from the Persian Gulf —will again be the capital of a revived power. Be this as it may, there is no doubt that the country can be benefited largely by the improvement of the navigation of both the Euphrates and the Tigris, and that a ship canal to accommodate the largest vessels could be constructed, at any rate, from the Persian Gulf to Babylon.

Asia.

The question of the Asiatic Euphrates Valley route to India demanded the special notice I have given to it. But in other parts of Asia, besides the regions of Asia Minor and Mesopotamia, and excluding also India, fields seem to be opening for the employment of British capital and British engineers. A pioneer railway has been completed from Jaffa to Jerusalem, under French auspices. It does not enter the sacred city, but terminates outside the Jaffa Gate. But it is under contemplation to construct therefrom a branch to Gaza, with the object, it is said, of forming a junction with a line from Egypt. Major Conder, R.E., who commanded for six years the Palestine survey, refers to a Carmel-Damascus line, as likely to be by far the best in order to develop the Syrian country. It would start from Haifa under Mount Carmel, which is one of the best roadsteads on the whole coast. It would traverse the Kishon Valley to the plain of Esdraelon, then descend down the valley of Jezreel and cross the Jordan. It would then ascend and pass through the rich plain of Bashan, which produces excellent crops, by following the valley of Jermuk, and when the plateau is reached the rest of the line would be along the old Roman highway to Damascus, a city with two hundred and fifty thousand inhabitants. This line would not pass through any of the holy places—an occurrence which would have been repugnant to many. Both Nazareth and the Sea of Galilee are some few miles to the northward. In a Jewish memorial presented last year to Lord Salisbury, the memorialists said with respect to Palestine and Syria—

> "If at this moment the ground is barren in parts and refuses to yield its increase, we know it is the hand of man that has wrought the evil. The hand of man shall remedy it."

It is not too much to expect that we as engineers may have our share in this beneficent work of renovation.

In the Asiatic Kingdom of Siam, a country having as large an

area as the United Kingdom, and which is under an enlightened ruler, railways are beginning to be constructed. The first sod of a line was cut by the king of that country in August of last year with oriental *éclat*. This line, uniting Bangkok, the capital, with the mouth of the river of that name, although only some 15 miles long, is important as being the first, and it may in a measure dissipate the rooted antipathy of the nation to European innovations, for another line and one much longer has since been begun under British auspices. In connection with this I may mention that strenuous efforts were made by the Germans to secure the contract for this railway, but the attempt failed. I ventured to predict in this Institution in 1879, when a Paper was read on "Railway work in Japan," that before long the Siamese would begin the construction of railways in their country as they were at that time preparing the way. It is to be expected, now that we have secured a good footing in Siam, that future works will be undertaken by British hands.

In Japan, much has still to be done, especially in the construction of harbours, and it is to be hoped that as this nation and Siam prosper, as they assuredly will by the construction of works that bring them more in contact with the outer world, the neighbouring nation of China will learn the lesson of the national evil of isolation. As regards that country, if ever it is to be opened to the foreigner, the work that will have to be done will be great indeed if it is to satisfy the wants of its teeming millions of inhabitants. The recent outcry against foreigners may be only the beginning of the end of Chinese exclusiveness, and if railway and other works are constructed, the Chinese as a nation are too alive to their interests to underrate what they would find to be of real value to them, not only socially, but—born traders as they are said to be—commercially and financially also.

South and Central America and Mexico.

Turning from the Continent of Asia to that of South America, to Central America, and to the adjoining country of Mexico in North America, we see to what extent trade binds nations together in common interests so that if one country suffers others suffer with it. Hence the collapse beginning in the Argentine Republic and Uruguay has indirectly affected and caused a cessation in the progressive development of the other Spanish-speaking Republics of South and Central America, and of Mexico, and of the Portuguese-speaking Republic of Brazil. European

capitalists and financiers (mostly British) who found the money for the prosecution of public works have collapsed or become straitened and cautious, merchants and manufacturers of all kinds have been weakened, and, under the pressure, engineers who carried out works in these countries—which have had to be suspended instead of new ones being initiated—have suffered much. We naturally ask the question, will there not be a revival in these countries? To this, I think, a hopeful answer may be given.

Thus, looking at the Argentine Republic, we see a country nearly as large as the whole of Europe, excluding European Russia, the land for the most part excellent, and a great portion of a kind on which cattle and sheep may be pastured without any clearing, and which may be brought into agricultural use. The country only needs railways, harbours, docks, and in some parts irrigation works, to develop it, and if normal conditions are re-established and maintained, many years must elapse before the work of the engineer will be accomplished.

A work that my firm are carrying out at Buenos Ayres, the Federal capital of the Argentine Republic, promoted by Mr. Eduardo Madero, and sustained by the ability, zeal, and energy of himself and his sons, will probably do more than anything else to resuscitate that country. The whole frontage of the city, a length of 3½ miles, is now being covered with docks. A channel some 14 miles long, together with a branch channel 6 miles long, is being dredged to bring ships from the present anchorage into the docks, the longer channel being in use, although still in an unfinished state. The port has a large trade, and all the goods had to be conveyed from the anchorage to the city in small craft. By the construction of the docks and the dredged approaches the nation may benefit to the extent of £1,000,000 a year in the reduction of freight and landing charges—a saving eminently conducive to the prosperity of the Republic and to the expansion of trade, and returning a very high rate of interest on the cost of the works. The completion of these docks will doubtless lead to other works. Already it is proposed to unite all the railways having termini at Buenos Ayres in a central station on the land reclaimed from the River Plate by the Dock Works, and important dock extension, river and other works consequent upon the existence of the docks have been considered.

The general remarks I have made as to the resources of the Argentine Republic are applicable to the smaller State of Uruguay, a splendid country in itself, to Chili and Peru, to Mexico (a country about half as large as Argentina), and in a modified sense

to Paraguay, Bolivia, and Central America, where much has to be done, and will doubtless be done by British capital. Brazil does not, except in the southern part, possess so favourable a climate as some of the more southern republics of South America, but many British engineers have obtained advantageous employment there, and much has to be accomplished. Sir John Hawkshaw was requested by the late Emperor Dom Pedro to visit the harbours of the extensive coast (some 3,500 miles long) of Brazil and to report on them, which he did in 1875. He laid out plans for eight important harbours, two of which are under construction, and all of which will probably be executed. Rio de Janeiro, the capital, being naturally a sheltered roadstead was not included, but it is contemplated to construct there extensive works of accommodation by British capital. Subsequently also Mr. Hawkshaw and I, in conjunction with Sir John Hawkshaw, surveyed and laid out plans for two other harbours on the southern Brazilian coast, one at Desterro in Santa Catherina and the other at San Francesco on the southern Brazilian coast, and a railway to connect them with the Uruguay system of lines—works necessary for commercial and strategic purposes. A great part of the interior of Brazil has yet to be explored; but apart from this a magnificent and vast stretch of country which is known has yet to be developed, and rivers and navigations have to be improved, for the most part, doubtless, by our own countrymen.

Africa.

For some time to come it is to be expected that Africa will need the services of the British engineer. Upwards of 3,000,000 square miles (including Egypt), or about two-fifths of that vast continent, is now British, or under British protection—an area larger than the United States of America, and between twenty-five and thirty times larger than the United Kingdom. Such is the territory, the portion of which secured by the British when the delimitation of the zone to be occupied by different European powers took place being at present without the sphere of civilization, and only to be brought within it by railways, roads, harbours, river improvements, and pioneer works. The satisfaction of such kinds of work will be enhanced because travellers and philanthropists have urged that adequate means of communication into the interior is the only way whereby the curse of slavery can be annihilated. Without means of transit trade with the coast is impracticable excepting by slaves, paid porterage being too costly.

As far as matters have advanced at present, the French and Germans, aided by their respective Governments, seem likely to anticipate us in the construction of railways in the undeveloped territories of Africa allotted to them—at least, if expressed intentions indicate speedy performance. The French, who have already constructed lines in their Colony of Algeria, propose to extend the system by constructing railways to the southward through their newly-acquired territory to, or in the direction of, Lake Tchad, on the border of British territory, and the Germans have commenced the construction of a railway, some 200 miles long, from the sea-coast to the foot of Mount Kilimanjaro, wisely selecting a healthy spot as a first terminus, where their servants could migrate to recover strength if attacked by malarial fever. I have already mentioned how, in Asia Minor, the Germans have blocked our railway route to India, just as the French blocked our water route by the construction of the Suez Canal. Rivalry of this kind, legitimate though it be, ought to, and will, without doubt, stimulate the spirit of our country. The necessity of this is especially apparent in a new country, for those first in the field establish the trade routes which it is difficult at any subsequent period to divert, and so obtain advantages of a permanent character.

The two most important English companies which have been formed to develop the interior of British Africa, that is to say, the Imperial British East Africa Company, and the British South Africa Company, are fortunately guided by men of enterprise, quite alive to the necessity of action. And though the financial disasters of 1890–91 have for the moment checked British enterprise, it will no doubt, as it has before, revive. In the meanwhile, the blow that has been inflicted has reacted prejudicially on our country and on our profession, not only in Africa, but in all parts of the world. These two Companies, however, in spite of checks, have been quietly, and without external aid, doing a great deal of work which will facilitate future engineering and other operations.

Thus the Imperial British East Africa Company, which was incorporated by Royal Charter in 1888, and has acquired potential rights over a territory covering an area of 750,000 square miles, has already established customs along its sea-frontage, and is constructing roads, telegraphs, and various preliminary works to develop the resources of the country under its government. But the Company failed in its endeavour to construct a railway, and so vital is this to the preservation even of the territory in its integrity, that when partial abandonment became imminent, Parliament in March last voted a sum of £20,000 to enable a survey to be made for a railway from Mombasa, a port on the Indian

Ocean, to Victoria Nyanza, as a preliminary step, it is hoped, to its construction, which might cost a sum of £3,000,000, the distance being about 500 miles. If Government guaranteed this capital sum, the annual interest would amount to, say, £90,000. But as the railway would penetrate important slave routes, it is believed that there would be such a reduction in the annual "slave vote," that it would in itself, to some extent at any rate, cover the guarantee, apart from any revenue the railway might earn. The slave cruisers employed on the East Coast of Africa cost the country a sum variously estimated at from £100,000 to £150,000 a year, and it is a service that can only be conducted at a great risk of the lives of officers and men. The suppression of the slave-trade, and the consolidation of British dominion in this part of Africa, render the construction of the railway a political and humanitarian as well as a commercial question; other engineering works would follow for the development of the territory. Thus some 100 miles further north from Mombasa is the river Tana, and 200 miles still further north is the river Juba, at the boundary of the British sphere of influence. Both of these rivers, it is said, are, or can be, rendered easily navigable for miles into the interior, and the sources of the latter—which indeed has already been navigated for 400 miles—are on the confines of Abyssinia.

The other Company I have referred to, the British South Africa, was incorporated by Royal Charter in 1889, having its principal field of operations in that part of South Africa which lies to the north of Bechuanaland and to the west of Portuguese East Africa. The Company has effected the peaceful occupation of Mashonaland. Many mining claims have been located and several companies formed for the development of the mineral wealth. And under the recent treaty between Great Britain and Portugal railway communication through the Portuguese territory between Mashonaland and the sea coast has it is said been arranged, although no railway works have as yet been begun.

As regards the African territories which are more settled, efforts are at present being made to construct railways in the Transvaal and the Orange Free States with British capital, and it is said that these lines will be remunerative.

In another part of Africa my partner and I were recently called upon to survey a railway from Freetown (the capital of Sierra Leone) to a short distance into the interior, a line capable of indefinite extension to the eastward. At the same time we designed a commodious harbour with a graving-dock for Freetown. The surveys we entrusted to the care of Mr. G. H. Stephens, Assoc. M. Inst. C.E.

Such a harbour is much required—the West Coast of Africa being singularly destitute of harbour accommodation, either for general commercial purposes, for coaling-stations, or for repairing ships.

The resources of Egypt are also, it is believed, capable of an important development by a work proposed by Mr. Cope Whitehouse, M.A., which has attracted considerable attention. As the result of his researches, it has been ascertained that a large depression called the Raian Basin, exists south-westward of the Fayoum, its northern extremity being opposite Beni-Souef, about 70 miles south of Cairo. Now it is well known that there is not sufficient water to irrigate the whole of the Egyptian delta which might be brought under cultivation, and in order that there may be, the summer supply must be considerably increased.

It appears that the whole delta was in former times under cultivation, which, as Mr. Cope Whitehouse says—

"Was in itself a conclusive proof that a storage reservoir had once existed," and he adds that "the explicit statements of Herodotus and others showed that the Nile had been regulated by utilizing a depression in the desert corresponding in shape and situation to the Raian Basin. It had been converted into an artificial lake which controlled the flow of the Nile, averted its excessive rise, and made provision against the annual recurrence of drought."

Lieut.-Colonel Western, R.E., Assoc. Inst. C.E., also approves of the proposal, and shows that the Raian Basin might be utilized with immense benefit to Lower Egypt. Other competent authorities have arrived at the same conclusion. It is estimated that the cost of converting the Raian Basin into a storage reservoir with contingent works of supply, regulation and distribution, would amount to £1,000,000. But the yearly revenue which would be derived therefrom would, at the end of a few years, it is said, amount to £3,000,000. The total yearly revenue of Egypt is about £10,000,000. No wonder, therefore, the Egyptian authorities take a lively interest in an undertaking which would be so highly remunerative, and of such vast benefit to the country.

The resources of Egypt are further capable of important development by the improvement of the first cataract (so-called) of the Nile at Assouan, the ancient boundary of Egypt. In 1865 I, in company with Mr. Hawkshaw, surveyed the district at the request of the then Khedive of Egypt—Ismail Pasha. We found that, by the construction of a work consisting of one lock and a short-cut, which would in no way interfere with the régime of the river, and which in this country could be executed for £250,000, the steamers and craft which navigate up to the first cataract and can go no further, could at all times proceed to the second cataract at Wady Halfa, some 200 miles higher

up. The prosecution of this scheme has always been a part of the programme of the Egyptian Government, and as it is a most important work, and as Egypt is getting more prosperous from year to year, it is not unlikely that it will soon be accomplished.

In Egypt the railway system extends up the Nile Valley as far as Asyût, a distance of upwards of 350 miles from Alexandria. It is gradually being continued up the Nile towards Assouan, which is upwards of 700 miles from Alexandria. Doubtless, before long, it will be extended even to the sources of the Nile by British aid. Indeed, it is not overstraining probabilities to expect, that before many years have elapsed, and considering the events which have recently led to the almost complete occupation of Africa by European powers, there will be through railway communication from north to south, and from east to west, and many other lines in that vast territory, besides internal water communication. Thus, in anticipation of the completion of the railway between Mombasa and Victoria Nyanza, the question of placing steamers on that great lake has already been mooted, in order to open what has been called the "rich and prosperous" Uganda country, said to be the key of Africa and destined to command the Nile basin. Further, looking to the future, some expect to see the day when the internal communication will be further perfected by constructing a railway between Victoria Nyanza and Albert Nyanza, through Uganda, placing steamers on the latter lake, out of which the Nile flows, and is navigable for some distance, until the first rapids are reached, improving them and the other rapids, or so-called cataracts, of the Nile by locks and cuts, or introducing ship-railways at the several obstructions to the continuity of the navigation. In fact, there appears no limit to the useful works that have still to be constructed throughout Africa.

The undertakings I have referred to in Egypt could, however, never be realized were the country left to itself. It is only those who know what Egypt was before the British occupation, who can appreciate the significance of the great changes which have resulted from the present beneficent control. I am not competent to deal with the political aspects of the general question; but from the standpoint from which I am regarding it, I can confidently assert that were the British control removed or weakened, the material development of the country would be arrested, and Egypt, if left to itself, would soon again become the miserable and unhappy country it was under the old régime. Such a state of things also would react prejudicially on other African territories, and in a manner on our own country also.

Engineering Literature.

There is one point I may notice, and it is a matter upon which Sir John Hawkshaw used frequently to remark. It is somewhat surprising, considering the number of books that have been written on almost every conceivable subject, that there has been no complete consecutively written treatise of the History of the Railway system—a system which has more than anything else been the means of revolutionizing the world and advancing the healthy progress of the human race. Those who could best have written it have either passed away or are advanced in years. The task every year becomes less easy of accomplishment. No one would be more capable of grasping the question than an engineer who, like some of our Members, cultivate or take an interest in the literature of our profession. It is to such that I commend the suggestion.

Concluding Remarks.

The time at my disposal has only enabled me just to take a rapid glance of a few matters bearing upon the future of engineering, confining myself to some works in this and other countries which will be carried out for the most part, in all probability, by British capital and by the British engineer. I have not ventured to touch upon the development of engineering in India. Nor in our colonies, as this subject three years ago formed the text of the late Sir John Coode's Presidential address. Neither have I noticed the future possibilities of electrical engineering, which in itself would form a subject for many addresses; nor of mechanical engineering, irrigation, shipbuilding, and gas and mining engineering. Had time permitted, I should have also liked to say a word on ship-railways, like that being constructed across the Chignecto Isthmus under the direction of Sir John Fowler, Bart., and Sir Benjamin Baker, which, if it prove a commercial success, as it will surely be an engineering one, will undoubtedly lead to the construction of others.

Also I should have liked to take up the question of large ship-canals, particularly the Nicaragua Canal, the designs for which, explained to me by Mr. Menocal, the engineer, have been so well worked out by him. This enterprise is perfectly feasible, and will be carried out if the American Government assist in financing it as it is now believed they will. It is true it will for the most part

be constructed under the direction of American engineers; but its existence will have such an important bearing on the trade of this country, and on the development of others, and indirectly on our profession, and is a work of such political importance, that now it is likely to be accomplished an allusion to it, however brief, should not be omitted.

Our profession is a vast one, and our Institution embraces every branch of it. This is owing to the broad lines of our Charter, which defines engineering to be "the art of directing the great sources of power in nature for the use and convenience of man." I have shown, I hope, that our profession is full of vitality. Instead of being on the verge of finality, it is probable that the next fifty years will witness a large development; and this may to some extent be gathered from the superficial forecast I have ventured to make of the future, and from the fact that money for executing public works can now be raised by responsible corporate bodies at a much lower rate of interest than was possible a few years ago. And whilst the thought of this probable development will, I hope, stimulate all of us who are pursuing our calling, it will, I trust, dissipate any dismal forebodings of my younger professional brethren who hold the mortgage of the future, who have the battle to fight, and who may more or less in times of depression like these have natural misgivings. A satisfactory feature also is the necessity which more and more exists for an engineer to take up one branch only of the profession as a speciality. When I began my career it was customary for many engineers to take up several branches; but, owing to increase of knowledge and the development of each branch, such is no longer possible. In this respect, apart from the multiplication of undertakings, there is room for the employment of more engineers than otherwise would be the case.

In his Presidential address, delivered before the British Association at Bristol in 1875, Sir John Hawkshaw concluded by saying, "We may never discover a new force; yet who can tell?" But if this be not so, we may at any rate utilize known forces not yet brought under control. Thus, for instance, we hear from time to time of proposals to utilize the tidal energy and the falls of Niagara. Indeed, it is reported that preparations are almost completed to accomplish the latter purpose on an extensive scale, the intention being to use part of the power brought under control in factories, and part in the electrical transmission of power. But Professor Crookes, F.R.S., says it has been computed that in a single cubic foot of ether, which fills all space, there are locked up several hundred foot-tons of energy. Energy being mass multi-

plied by half the square of the velocity, the velocity of the ether particles is said to be so enormous that a very small mass will be sufficient to give very many foot-tons of energy. The idea is supported by some physicists and mathematicians; it is objected to by others, the point in dispute being the density of the ether particles. The latest researches, Professor Crookes says, warrant the statement that this vast storehouse of power cannot be pronounced to be hopelessly inaccessible. This, at any rate, seems something like a new force for the engineer to "direct for the use and convenience of man," if it can possibly, as Professor Crookes and some others think, be brought under control.

In conclusion, an important duty devolves on me. It is to thank you for the honour you have conferred on me in electing me President of our Institution. It is the goal to which every engineer aspires. The attachment I have to our Institution and to the profession to which we belong, will, I trust, with the aid of the many friends I see about me, operate in enabling me to perform satisfactorily the responsible duties I have been called upon to undertake.

The social standing of our profession has in recent years been largely raised, and is still rising, owing to the fact that engineers are now much more highly educated than formerly, and must be if they are to obtain success in their calling, and to compete with foreign engineers in the field of the world. And owing, also, I venture to say, to our Institution, for not being controlled by any special Act of Parliament, the profession comes to be very much what the Institution makes it. At least, I for one have long thought so; and this surely should be an incentive to any President, urging him to action, so that the prestige of the Institution of Civil Engineers shall be maintained and enlarged, and with it the dignity and the efficiency of our interesting and useful calling.

On the motion of Sir Charles Hutton Gregory, K.C.M.G., Past-President, seconded by Mr. Abernethy, Past-President, it was resolved by acclamation:—

"That a cordial vote of thanks be passed to the President for his Address, and that he be requested to allow it to appear in the Minutes of Proceedings."

The President, after acknowledging the resolution and consenting to the publication of his address, proceeded to distribute the Telford Medals and Premiums, and the Miller Prizes awarded by the Council for the Session 1891–92 (vol. cx. pp. 197, 210.)

15 November, 1892.

HARRISON HAYTER, President,
in the Chair.

(*Paper No. 2516.*)

"Halifax Graving-Dock, N.S."

By the Hon. Richard Clere Parsons, M. Inst. C.E.

The City of Halifax, Nova Scotia, is the eastern terminus of the Intercolonial Railway; its harbour is the winter port of the Dominion Government on the Atlantic coast, and the chief British naval station in North America. It is also a port of call for the Allan and Dominion lines of passenger-steamers, as well as for several transatlantic Canadian and United States trading lines.

The construction of a graving-dock having been considered for several years, much attention had been given to the relative merits of stone and wooden docks. Stone has not been much used for this purpose in the United States in recent years, a preference having been given to docks constructed of wood and backed with puddle, as at Portland, Boston, Brooklyn, and other places. The arguments in favour of wooden docks are:—that they are cheaper to construct, and, in a climate where the variation in temperature is great, they are more comfortable for the men employed in them, being cooler in summer and warmer in winter than stone docks; further, that they dry sooner, and when ice forms, it is more easily removed from them than from stone or concrete docks: on the other hand, the latter, if properly constructed, are more durable, and require little or no expenditure for repairs.

The Halifax Graving-Dock Company was formed in 1885. Agreements were entered into whereby the Corporation of the City of Halifax, the Dominion Government and the Lords of the Admiralty, undertook to subsidise the Company to the extent of $10,000 per annum on behalf of each of them, for a period of twenty years dating from the completion of the dock, on certain

conditions. The most important of these were that the dock should be of not less than the following dimensions:—

	Feet.
Clear length on the top from caisson-groove to head of dock. . .	580
„ „ bottom „ „ „ . . .	560
Width of dock at the top	102
„ „ bottom	70
Draught of water on the sill at high water of ordinary spring tides.	30
„ „ floor of dock „ „ „ .	32

In order to permit H.M.S. "Inflexible" to enter the dock, it was found necessary to make the width of the entrance at the top 89½ feet; and it was subsequently arranged to construct a second facing for the caisson at the extreme end of the entrance, by which means the available length was increased by 20 feet.

Site.—Several positions for the dock had been suggested, both above and below the city; and the site ultimately adopted was selected for the following reasons: (1) The position was believed to be sufficiently far down the harbour to avoid the likelihood of its being frozen over at any time to such an extent as to block the approach; (2) The centre line of the dock could be placed in an oblique direction to the general line of foreshore, so that vessels could enter and leave the dock with ease; (3) Communication with the Intercolonial Railway, by means of a siding, could be readily obtained.

Tides.—The difference between the high- and low-water levels at ordinary spring tides, in Halifax harbour, is 6 feet. The height of the tides is, however, much influenced by wind; and it has been found, by careful observation, that there is a difference of 3 or 4 inches between high water of the same tide at a point opposite the centre of the city, and at the dock; and, with certain winds, extraordinary high tides have also been known to exceed levels of ordinary spring tides by 2 feet, and extraordinary low tides have been noted 10 inches below low-water level of ordinary spring tides. Tidal observations, lasting over a period of several months, were taken on a gauge fixed near the site of the dock; and the high-water level of ordinary spring tides thus found corresponds very nearly with that determined by the Royal Engineers, after allowing for the known difference between tide-levels above and below the city.

Description of Dock (Plate 2).

Cofferdam.—The whole of the bottom of the dock is composed of rock into which it was useless to attempt to drive piles. The space under the site of the cofferdam, and for some distance on both sides, was therefore dredged to the rock surface, and all loose material was removed by divers. A large quantity of stiff clay was tipped from barges over this area; and piles were driven into it down to the surface of the rock. The dam was formed of two rows of piles 6 feet apart, braced together at as low a level as possible, the internal space being filled in with puddle, and, as the water was pumped out, it was securely stayed on the inside. The total length of the dam was 570 feet, and the greatest depth to the rock 33 feet below high-water of ordinary spring tides; the finished level of the top of the dam being $4\frac{1}{2}$ feet above high-water of ordinary spring tides. At both ends of the dam above the water-line, a trench was excavated to the solid rock, and filled with puddle. The area to be enclosed was divided into two sections by a cross dam, thus enabling the excavation of the dock to be proceeded with at the upper end, where it was shallowest, several months before the deep-water part was enclosed. The dam was commenced in August 1886, and was completed and the space pumped dry by May, 1887. No mishap of any kind occurred; and the amount of leakage was very slight, involving little or no pumping.

Excavation.—The spoil from the excavation of the dock, consisting almost entirely of a hard clay slate, was chiefly used to form the wharf on the water side of the dock; some of it being reserved for the rubble backing, and also to mix with sand and gravel for the concrete. The very small amount of land-water met with in the excavations was conveyed by drains, laid below the concrete, to the pump-well.

Bottom and Sides of the Dock.—The bottom of the dock was originally intended to be of concrete, 2 feet thick; but to meet the wishes of the City Corporation, it was arranged to have a pitch-pine floor laid on sleepers bolted to the concrete, which was reduced to a minimum thickness of 1 foot, Fig. 4; owing however to the irregularity with which the rock was excavated, this depth was generally exceeded. The flooring has proved a great convenience, as, when the dock is pumped out, the water drains away from the surface immediately. The sides, up to the level of the solid rock, were formed with a minimum thickness of

3 feet of concrete; and above this level, the walls consist of rubble-in-cement backing, faced with concrete of the same thickness as below. The altars are capped with granite, 12 inches thick; and a granite coping, $1\frac{1}{3}$ foot by $2\frac{1}{2}$ feet, runs all round the dock. There are three flights of steps on each side, giving access to the bottom, and three timber-slides. The entrance is constructed in a similar manner to the body of the dock, the caisson-groove being faced with granite quoins rubbed smooth on the bearing-surfaces. The concrete was composed of seven parts of broken stone, gravel and sand, to one part of Portland cement.

Caisson.—The dock is closed by a steel ship-caisson, built by Messrs. D. J. Dunlop and Co., of Port Glasgow, operated by means of capstans and tackle; and when the dock is open, the caisson is berthed in a recess alongside the entrance. When the work was nearly completed, it was thought advisable, in view of the growing tendency to increase the length of ocean-going steamers, to provide for the dock being closed by placing the caisson at the extreme outer end of the entrance. The ends having been built with a rounded arris, iron castings were placed in the wall to afford sufficient bearing surface for the keel and stems of the caisson to rest against.

Machinery.—The machinery for emptying the dock consists of two vertical direct-acting high-pressure steam-engines, having 19-inch cylinders with a stroke of 16 inches, working two centrifugal pumps 5 feet in diameter. The steam is supplied from 3 steel boilers, 5 feet 9 inches in diameter and 12 feet long, each having 36 tubes, $4\frac{1}{2}$ inches in diameter, and working under a pressure of 100 lbs. per square inch. The machinery was specified to be capable of emptying the dock, when full at high-water of ordinary spring tides, in four hours, the volume thus removed being about 1,472,000 cubic feet. The time actually required is considerably less than this. The engine-house floor is 17 feet below the coping-level. There is also a drainage-engine having a 10-inch cylinder, with a stroke of 12 inches, working a set of three-throw pumps, each 11 inches in diameter with a stroke of 2 feet 6 inches. This engine is supplied with steam from the main boilers. The water flows to the pump-well through a culvert, 6 feet by 3 feet, over the mouth of which a wrought-iron grating is fixed; and penstocks are placed on both the inlet and delivery culverts. The delivery pipes are provided also with reflux valves, where they discharge into the culvert, the mouth of which is below low water. The machinery was supplied and erected by Messrs. James Watt and Co., and has proved entirely satisfactory.

Entrance Channel.—A channel had to be blasted and dredged for some distance beyond the entrance to the dock, to obtain the requisite minimum depth of 30 feet at high-water of ordinary spring-tides. Part of the cofferdam was removed when the dock was sufficiently advanced to enable the entrance to be closed by the caisson; and the end of it, on the harbour side of the entrance was converted into a dolphin, to assist in guiding vessels into the dock. On the shore side of the entrance, two timber cribs were built for the same purpose, and also to prevent vessels on entering or leaving the dock from drifting into shoal water.

Wharf and Jetties.—From the wharf between the dock and harbour, 4 timber jetties were carried out a sufficient distance to ensure a depth of 30 feet at high-water. These jetties are 25 feet wide, and were formed by driving piles, of not less than 12 inches in diameter, into the rock debris, and flooring the top with 6-inch planks. The piles are in four rows, 7 feet apart both transversely and longitudinally; they are braced together longitudinally, and above high-water level transversely; but the transverse braces which were originally intended to be fixed below high-water level, were omitted, as it was feared that they would cause floating ice to accumulate and damage the structure.

Railway-Siding.—A railway-siding has been laid connecting the wharf with the Intercolonial Railway. Owing to the difficulty of arranging with the owners to allow the line to pass through the adjacent property, it was necessary to bring it to the wharf by means of a back shunt; and, as the available space would not allow of sufficiently easy curves being laid to accommodate the coal-trucks of the Intercolonial Railway, which are about 38 feet over all, a turn-table was placed near the head of the dock to obviate this difficulty.

Equipment.—The dock is furnished with keel-blocks of two patterns, as the Admiralty did not approve of the ordinary pattern used in commercial docks; they also required a certain number of bilge-blocks and tackle. There are the usual bollards, capstans, and fair-leads for docking vessels. The dock is well provided with machinery and tools for ordinary repairs; it is lighted by electricity; and a good supply of water is laid on from the city main. The works were commenced on May 1st, 1886, and were opened by Vice-Admiral Watson, Commander-in-chief on the North American station, on September the 20th, 1889. The manner in which the contract was arranged renders it impossible to fix

the total cost. Mr. Bateman's preliminary estimate, however, for a dock of somewhat smaller dimensions than those ultimately fixed upon, was £135,000. This sum did not include many of the requirements of the subsidizing parties, which were afterwards added. Up to the present time the use of Portland cement concrete has been amply justified, the only effect of the frost having been to cause a slight scaling-off of the plaster facing which had been used to give the surface a smoother appearance.

The work was carried out in a most satisfactory manner by Messrs. S. Pearson and Son, Westminster, from the designs of the engineer, the late Mr. J. F. La Trobe Bateman, Past-President Inst. C.E.; Mr. E. H. Keating, M. Inst. C.E., City Engineer, was Mr. Bateman's representative in Halifax; and Mr. William Fox, M. Inst. C.E., attended to the engineering details in England, and also visited Halifax previous to the work being commenced. After Mr. Bateman's death, in June 1889, his successors in business, Messrs. Bateman, Parsons, and Bateman, were appointed engineers, and superintended the completion of the work.

The dimensions of several graving-docks in the United States, and of those at Quebec and St. John's, Newfoundland, are given in a tabular form in the Appendix. It will be noticed that the Halifax dry-dock, although second in length, exceeds in depth, floor-area, and cubic capacity, any other dock on the Atlantic coast of North America.

The Paper is accompanied by drawings, from which Plate 2 has been prepared, showing, in addition to the general details of the dock, both in plan and section, its situation in the Harbour of Halifax.

APPENDIX.

Dimensions, etc., of the Principal Dry-Docks on the Atlantic Seaboard of North America.

Place.	Number.	Material of Construction.	Length on Bottom from Inner Groove to Head.	Length on Top from Inner Groove to Head.	Length on Top from Outer Groove, or Abutment, to Head.	Width on Top in Body.	Width on Floor in Body.	Width of Entrance at Coping.	Width of Entrance at Bottom.	Depth of Sill below Coping.	Depth of Sill below H. W. O. S. T.	Height of Coping H. W. O. S.	Remarks.
			Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	
1. Halifax	1	concrete and stone	560	580	600	102	70	89½	81	34½	30	4½	Finished in 1889
2. Quebec	1	stone	533	534⅓	551⅓	100	72	68	65½	33½	26½	7	
3. Newfoundland	1	wood	600	558	—	132	50	85	—	—	25	—	
4. Portland	1	wood	390	425	425	100	45	80	45	27	22	5	Finished in 1870
5. ,,	2	wood	180	200	200	80	40	40	40	17	12	5	,, 1871
6. Charlestown Navy Yard	1	stone	293	318	389	80	30	60	44	30	25	5	Finished in 1832, and extended 65 feet in 1859
7. Boston	1	wood	340	365	365	100	45	68	68	24	18	6	Finished in 1864
8. ,,	2	wood	240	250	250	75	45	45	45	22	16	8	,, 1854
9. ,,	3	wood	155	165	165	45	30	35	35	21	15	6	,, 1855
10. Brooklyn Navy Yard	1	stone	328	358	370	100	30	68	48	30	25½	4½	,, 1851
11. Cramps Dock, Brooklyn	1	wood	465	500	520	124	52	100	46	26	22	4	,, 1866 Lengthened and deepened in 1881
12. Cramps Dock, Brooklyn	2	wood	567½	600	620	115	46	85	45	30	25	5	,, 1866 Lengthened and deepened in 1881
13. Cramps Dock, Philadelphia	1	wood	415	430	450	111	45	70	48	24	20	4	,, 1876
14. Norfolk Navy Yard	1	stone	261	290	290	86	30	60	44	30	25	5	,, 1834
15. Baltimore	1	wood	437	450	470	111	45	80	48	27	22	5	,, 1880

(*Paper No. 2499.*)

"The Biloela Graving-Dock, Cockatoo Island, Sydney Harbour, N.S.W."

By Edward William Young, M. Inst. C.E.

Cockatoo Island, the site of the new graving-dock in the harbour of Sydney, New South Wales, is situated in the Paramatta river, some 2 miles above Dawes Point. It is a rocky island, rising about 50 feet above sea-level, and separated from the mainland by channels about $\frac{1}{4}$ mile wide. A convict establishment was established there some time ago, the buildings of which were constructed by convict labour; which was also employed in forming the Fitzroy graving-dock on the island, subsequently lengthened to about 500 feet. This dock is capable of taking a 4,000-ton steamer; but it has not sufficient depth or width for the largest man-of-war, or merchant steamer. It was mainly hewn out of the solid rock, and the material so obtained, together with a large amount of overlying rock, was utilized in forming level ground, on which work-shops and dwellings have been erected, making a considerable addition to the area of the island. The upper altars on the southern side were built of sandstone from the excavations; and the remaining portions of the dock were formed of natural rock, except where it was found to be unsound.

To meet modern requirements, a new dock was designed, under the instructions of Mr. E. O. Moriarty, M. Inst. C.E., late Chief Engineer for Harbours and Rivers, by Mr. J. B. Mackenzie, M. Inst. C.E.

The principal dimensions are as follows:—

	Feet.
Extreme length from outer stop-quoin to head of dock at coping-level	638
Extreme length from inner stop-quoin to head of dock at coping-level	608
Length of floor	580
Width between piers	88
Width at coping-level	108
Width at entrance	84
Depth of sill below coping	37
,, ,, H.W.S. tides	32
,, ,, L.W.S. tides	26
Depth of floor below coping at head of dock	39
,, ,, sill ,,	40·5

Preliminary Excavations.—The preliminary work down to the coping-level, forming contract No. 1, was commenced in February 1883, and completed by the end of the year. It comprised the excavation of 50,000 cubic yards of rock, 17,000 cubic yards of soft soil, and 2,700 square yards of scabbling, and was performed for less than £10,500.

Graving-Dock.—Contract No. 2 (Figs. 1 and 2, Plate 3), which was let to the late Mr. Louis Samuel, included a cofferdam at the entrance, and all the necessary works, with the exception of the engine- and boiler-houses, and the preparation of the sub-aqueous foundations for the sea-walls. The foundations for the sea-walls were carried out by day-labour, under the Engineer in Charge. The engine- and boiler-houses formed a supplementary contract; the pumping-machinery was let to Messrs. James Watt and Company, and the caisson to Messrs. Easton and Anderson. Work was commenced early in 1884; and, as the ground fell away towards the sea on the southern side of the dock, a concrete wall had to be built to exclude the water. A trench was accordingly cut down to the solid rock, and filled with well-punned concrete. As the work proceeded, the unequal quality of the rock, and the patchy appearance that would result from the adoption of a mixture of rock and ashlar for the face, led to the abandonment of the original idea of cutting the rock to the profile of the altars where suitable. Accordingly, the whole of the upper altars, on both sides of the dock, were constructed of sandstone ashlar, while the broad altar and copings were of granite; the lower altars being formed of bluestone concrete, mainly in consequence of the difficulty of obtaining sufficiently good stone from the excavations.

Dock-Floor.—The rock having been excavated to the required depth, a 12-inch layer of concrete, formed of 1 part of Portland cement, 2 of sand, and 4·91 of broken stone (one-third of shivers and two-thirds of 2½-inch gauge bluestone metal), was spread over the bottom; and upon it were bedded, in cement mortar of 1 part of cement to 2 of sand, the bluestone blocks 12 inches thick. These form the floor, which, besides a longitudinal fall, has a lateral fall from the centre-line to each side. A gutter 1 foot 6 inches wide, separates it from the lower altars.

Lower Altars.—These are formed of bluestone concrete, consisting of 1 part of cement, 2 of sand, and 5·07 of broken stone, (one-third being of shivers and two-thirds of 1½-inch gauge). They are faced with a 2-inch layer of fine concrete, composed of 1 part

of cement to 2 of quartz gravel, passed through a $\frac{1}{4}$-inch, and caught on a $\frac{1}{8}$-inch mesh-screen, and washed thoroughly clean. Their upper surfaces are roughened by hammer-dressing.

Broad Altar.—The lower altars are separated from the upper ones by the broad altar of granite, $2\frac{1}{2}$ feet thick and 4 feet wide, excepting at the piers, where it is only 2 feet wide. Its upper surface is $23\frac{1}{2}$ feet below the coping-level. Skew steps of granite, let into the lower altars, afford access from the broad altar to the floor.

Upper Altars.—The blocks, except in special courses, are $1\frac{1}{2}$ foot thick, dressed to level beds, stretchers being not less than $4\frac{1}{2}$ feet by $2\frac{1}{2}$ feet, and headers not less than 4 feet by $2\frac{1}{2}$ feet. Vertical joints have a band of not less than 12 inches. There are four upper altars, each 4·7 feet in height, the upper surface of the highest being 4·7 feet below the coping-level. The edges of all altars are rounded.

Coping.—The granite coping has generally two stretchers to every header; the former are 3 feet wide and $1\frac{1}{2}$ foot deep, of variable length; the latter are 4·7 feet deep by 4 feet by $2\frac{1}{4}$ feet. For the entrance and sea-walls, the copings are somewhat heavier.

Piers, Steps, and Slides.—There are three piers on each side of the dock, 30 feet wide at the coping-level, which serve to support flights of granite steps connecting the quay-level with the broad altar. These piers are protected by fenders of iron-bark, 12 inches by 12 inches, let $1\frac{1}{4}$ inch into the masonry, and secured by wrought-iron bolts. Access to the broad altar is also given by two flights of granite steps at the head of the dock. Timber-slides, 4 feet wide, are laid alongside these steps; four slides on each side of the dock are also provided.

Inverts.—The inverts and invert-walls are formed of sandstone ashlar, with granite quoins; the inner invert is 20 feet, and the outer invert 15 feet broad; the joints, of about $\frac{1}{8}$ inch only, were made in mortar of 1 part of cement to 1 of sand; the quoins were set in neat cement. For setting the stones, a timber staging, carrying a powerful traveller, was erected across the dock at each invert in turn. The meeting-faces were gauged to true vertical planes by wires tightly stretched across the dock, supplemented by vertical and inclined wires. The plane of the wires was fixed parallel to that required for the stop-quoins, and distant from it a few inches only. The stones were adjusted by means of a distance-piece applied to the wires. The meeting-faces were 14 inches broad, and projected $\frac{3}{4}$ inch. The faces of the stones were ground together in pairs before setting

them in place. Only a moderate amount of grinding, however, was afterwards required to obtain a true plane and form a water-tight joint with the caisson. Where the rock was sound, the ashlar of the invert-walls was toothed into it; but elsewhere a backing of bluestone concrete was provided. The backing throughout the dock consisted generally of sandstone rubble, or of sandstone concrete in confined spaces, formed of 1 part of cement, 2·5 of sand, and 5·1 of broken stone gauged by a $2\frac{1}{2}$-inch ring. Whenever the surface of the rock excavation was not sufficiently irregular, holes were cut in the rock to afford the necessary key for the masonry.

Entrance-Walls.—The round nose at the entrance on the south side projects 37 feet, and that on the north side 62 feet beyond the stop-quoin of the outer invert. The walls are formed of concrete up to a level of 1 foot above low-water mark, and of sandstone ashlar above, with granite coping. The concrete wall has a batter of 1 in 24, and is 11 feet thick at the top.

Sea-Walls.—The sea-walls are also of concrete, with a batter of 1 in 8. That on the south side is 11 feet thick at the top, and that on the north side 9 feet. The masonry of the upper part is similar to that of the entrance-walls. Both are backed up with hand-packed rubble, 10 feet thick, above low-water mark. The ashlar varies from 7 to 8 feet in thickness. The greater part of the concrete in these, and the entrance-walls, was deposited under water; it was composed of 1 part of cement, 1·5 of sand, and 3·61 of bluestone gauged by a $2\frac{1}{2}$-inch ring. Before it was deposited, the bottom was prepared by divers assisted by dredgers. A grab-dredger was used first to remove as much as possible of the clay and mud overlying the rock. Then divers were sent down, who further cleared the rock, and broke up loose boulders. In general, as the foundations were situated at the base of a submerged cliff, a great quantity of loose rock embedded in stiff clay had to be removed; so that, after the divers had broken up all the boulders in sight, and these had been removed by the Priestman grab, a second or third layer had to be dealt with, and the grab used again. When a sound, solid bottom was reached, it was levelled or roughened by divers. The foundation having been prepared for a length of not less than 25 feet of wall, a timber framing was erected over the site, the vertical posts of which were either let into sockets in the rock, or connected therewith by iron pins. To these posts horizontal walings were secured; and to them the vertical planking was fastened, the inside being lined with canvas. The bottom was

then thoroughly cleaned by a jet of high-pressure water; after which the concrete was lowered on to it in skips, containing about 1½ cubic yard, with a bottom formed of two flaps secured by a catch that could be released by pulling a rope. The deposition was carried on night and day until the wall reached a height of 6 inches over the required level of 1 foot above low-water mark. The materials were at first mixed dry, placed in the skips, and then lowered. The unavoidable inrush of water, however, which occurred on the withdrawal of the skip, carried a large quantity of the cement to the surface, where it formed a thick scum. The concrete was therefore moistened before being lowered into position; and, as it was found that in this way less scum was formed, the system was subsequently adhered to. The concrete was deposited in lengths of between 25 feet and 50 feet, each connected with its neighbour by a joggle. From the upper surface, a three-inch layer of impoverished cement, of the consistency and strength of putty, had to be removed before sound material was reached, upon which the lower masonry courses were founded at low-water.

Timber Wharf.—The quay accommodation on the south side was extended by a timber wharf, 222 feet long and 28 feet wide, consisting of a 4-inch flooring supported on piles of iron-bark, which, together with the other timber-work below high-water mark, were protected by sheet muntz-metal, against the attacks of the teredo. The piles in the outer row were slightly tapered at the foot, and driven into circular holes drilled in the solid rock. The piles in the inner row were driven, in the ordinary way, into the clay near the shore.

Sluices.—The two inlet-sluices, 6 feet by 4 feet, are closed by Stoney balanced valves. The southern inlet is generally used; the northern being reserved for emergencies. This latter was employed in filling the dock, before the cofferdam at the entrance was removed, for the purpose of testing the caisson and engines. The channel conveying the water to the pump-wells is 7 feet by 5 feet, protected by an iron grating. It can be closed by a Stoney valve, so that the engines may be used in pumping out the Fitzroy dock, which has been put into communication with the pumps by a circular culvert 3 feet in diameter, formed in the cement backing of the broad altar on the north side of the dock, and by tunnels—one driven through the rock, which separates the Fitzroy dock from the head of the new dock; and a shorter one, which connects the western end of the culvert with the pump-wells, and can be closed by a valve.

Caisson.—The caisson (Figs. 3 and 4, Plate 3) is of wrought-iron, 90 feet long by 14 feet 9 inches wide, and 39 feet 1½ inch deep from deck to keel; it is furnished with a balanced falling deck on Kinipple's principle, and it rests on delta-metal rollers 18 inches in diameter. Flotation is obtained by means of an air-space included between water-tight decks, 8 feet 10 inches apart, the upper deck being just below low-water mark of spring tides. Below this chamber, the water has always free access to the interior of the caisson, and above it also, when the caisson is in place. When the caisson has to be floated for moving it in or out of place, the water can be excluded from the interior, above the upper water-tight deck, by closing a valve. A lift of 5 feet from the bearings can thus be obtained at high-water, allowing the caisson to be swung round without fouling the masonry of the inverts. The meeting-faces of the caisson are formed of Jarrah timber, bedded in chunam, caulked, and carefully dressed. The caisson when tested made a satisfactorily water-tight joint with the masonry on both faces.

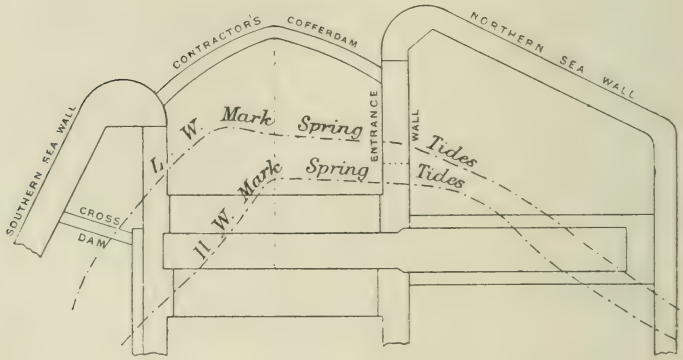
Caisson Hauling-Gear.—By means of a strap, and a pin which can be withdrawn, the caisson is connected with a crosshead, the ends of which are attached to endless chains driven by spur-wheels and gearing situated at the northern end of the caisson-chamber, and connected by shafting with the small drainage-engine. An adjustable clutch is interposed between the shafting driven by the engine and the spur-wheels. This clutch can be actuated by a lever, so as to haul the caisson inwards or outwards without reversing the engine. To prevent over-winding, or fracture of parts, through any accidental extraordinary resistance of the caisson, an automatic epicyclic disengaging-gear has been provided, which consists essentially of four mitre-wheels, the two in the line of the shafting gearing into two others, at right-angles to them, through which the power is transmitted. Powerful springs pressing on their common axle prevent it from revolving in the plane at right-angles to the driving-shaft. Should, however, the resistance offered by the caisson exceed 26 tons, the action of these springs would be overcome, and a transverse movement of the bevil-wheels commence, disengaging a falling-weight which, striking a bent lever, would disconnect the shaft from the friction-clutch on the axle of the engine, and at the same time shut off the steam.

The erection of the caisson and its hauling gear was undertaken by Mr. E. L. Samuel, for Messrs. Easton and Anderson. A timber cradle having been laid at the bottom of the dock, the caisson was

built thereon, and floated into position when completed, water being admitted into the dock for this purpose.

Cofferdam.—The construction of the sea-walls outside the cofferdam was proposed to be deferred until the work inside had been done. Shortly after the operations were commenced, however, the contractor requested to be allowed to utilize the concrete sea-walls as part of the cofferdam. The Government, in approving the proposal, required him to place his cofferdam a little further seaward, where a flat ledge of rock afforded a favourable site. A considerable amount of excavation in rock, which would have had to be done under water, could thereby be done in the dry; and the contractor agreed to this modification, on condition that 5*s.* per cubic yard extra should be allowed on

Fig. 1.



the excavation under water thus saved. In consequence of this change of plan, the erection of the sea-walls had to be proceeded with at once. It was first intended to make the cofferdam co-extensive with the sea-wall of the quay, on the north side of the dock; but, as the preparation of the foundations proved very tedious, it was decided to curtail the cofferdam by using the entrance-wall on the north side instead of the quay wall. This, and the entrance-wall on the south side, having been completed, the contractor built the cofferdam (*Fig. 1*) of concrete—deposited under water—across the entrance. In this case broken sandstone was employed in lieu of the bluestone used for the permanent work. The contractor had also to construct a small dam, known as the cross-dam. In April, 1887, about thirty days after the completion of this cross-dam, the level of the water on the inside

was lowered a few feet, and some temporary shores were put in as a precaution against collapse. The water was then fully pumped out; and, after the back of the wall had been exposed for about a fortnight to the hardening influence of sun and air, the shores were removed. The dam remained water-tight, and showed no signs of weakness. Under its protection, the excavation at the entrance was completed, and the inverts put in. While the works in the dock were in progress, the construction of the northern quay was pushed on, this forming the supplementary part of the cofferdam, under protection of which the excavation of the caisson-chamber was effected, and the remainder of the masonry executed. The water was first lowered inside this dam in December, 1887, and the concrete proved perfectly water-tight.

Boiler- and Engine-Houses.—The sinking of the pump-wells for the engines, and the erection of the boiler- and engine-houses, exclusive of the roofing, were let as supplementary contracts to Mr. Samuel. These buildings, including the roofing, were completed in July, 1888.

Pumping-Machinery.—The pumps consist of a pair of double-acting plungers, 54 inches in diameter, having a stroke of 6 feet. The water is admitted into the suction-chambers by flap-valves opening inwards, and is expelled through similar valves opening outwards. The condensing engines consist of a pair of horizontal cylinders, 38 inches in diameter, having a stroke of 4 feet. The boilers—three in number—are of the steel tubular type, working up to a pressure of 80 lbs. per square inch. The contract required the pumps to be capable of discharging 45,360 tons of water in three-and-a-half hours, the lift increasing from zero at high-water of spring tides to 36 feet at the bottom of the dock. The engines usually commenced their work at 22 strokes per minute, slowing down to 12 at the finish, and showed themselves capable of complying with the contract requirements. A small drainage-engine, for keeping the dock dry and working the caisson hauling-gear, was also provided. The machinery was supplied by Messrs. James Watt & Co., and erected by their agent, Mr. G. Smale.

Outlet-Culvert.—The masonry of the outlet culvert was executed by Mr. Samuel, as far as the stop-quoins for the flap-valve; the remainder was done by day-work under Government officers. A temporary concrete cofferdam was fixed across the entrance, and the excavation behind it effected in the dry. The self-acting balance-valve was then adjusted, the dam removed, and the

remainder of the rock excavation accomplished by blasting and dredging under water.

Embankment of Made Ground.—The spoil from the excavation under contracts Nos. 1 and 2 was tipped into the sea on the north and south sides of the island, and dressed to a level surface. On the south side, the embankment was covered with 9-inch sandstone pitching for a width of 90 feet from the edge of the coping; and was afterwards covered with a 6-inch layer of 2½-inch gauge bluestone metalling, blinded with a 2-inch layer of bluestone shivers. The remainder of the embankment on this side of the dock was covered with a 10-inch layer of sandstone, broken to 4-inch gauge, overlaid with 4 inches of bluestone metalling, and 2 inches of bluestone shivers, the whole being well watered and rolled. A projecting spur was formed at the eastern end of the embankment, to afford shelter for boats. By the works in connection with the dock, the area of the island has been largely increased.

Excavations beyond the Cofferdam.—When the caisson was completed, and the machinery was in working order, the excavation of the rock beyond the cofferdam was commenced. In order to save diving as much as possible, galleries were driven underneath the cofferdam as far seawards as was consistent with safety; and the remainder of the rock and the concrete cofferdam were then removed by divers, and by blasting and dredging operations. A considerable amount of dredging was executed in the harbour in the neighbourhood of the dock-entrance, to afford plenty of room for the turning of the large vessels expected to use it.

Cost of the Works.

	£.
Graving-dock	207,317
Pumping-machinery	15,478
Engine- and boiler-houses	6,441
Valves, moorings, cables, &c.	3,343
Caisson	17,140
Plant	7,517
Water-supply, roadway, &c.	2,639
Salaries	7,950
Total	£267,825

The time occupied in the entire work was from February 1883, to March 1890. Mr. E. O. Moriarty, M. Inst. C.E., the Engineer-in-Chief for Harbours and Rivers, having retired, and his successor, Mr. C. W. Darley, M. Inst. C.E., being absent on leave, Mr. R. R. P. Hickson, M. Inst. C.E., was appointed Acting Chief

Engineer until Mr. Darley's return in March 1889, under whom the works were completed. Mr. J. B. Mackenzie, M. Inst. C.E., acted as Resident Engineer from September 1881 to June 1886, and the Author from that date until April 1889, when the caisson was in working order. The Consulting Engineer in England for work was Sir John Fowler, Past-President Inst. C.E.

The Paper is accompanied by ten drawings and tracings, from which Plate 3 and the *Fig.* in the text have been prepared.

APPENDIX.

Cement, Mortar, and Concrete.

Portland cement only was used throughout the works, each consignment landed on the island being tested. Neat cement, setting in less than two hours, was required to stand a breaking tensile stress of 142 lbs. per square inch, and, if over two hours in setting, of 170 lbs. per square inch, the tests to be made twenty-eight days after it was made up into briquettes; the proportions being 1 part by weight of cement to 3 parts of clean sharp sand, to one-tenth part of their combined weight of water. Neat cement briquettes were required to stand a tensile stress of 400 lbs. per square inch after seven days, during six of which they had been immersed in water; and 550 lbs. per square inch after twenty-eight days, twenty-seven of them in water. Very little cement was brought on to the works which did not come up to this standard, which was generally much exceeded. The cement was spread on the floor of a weather-proof shed, to a depth of 3 feet or thereabouts, for a period of three weeks before being used in the works. This air-slaking was dispensed with in the later stages of the work, in the case of the concrete deposited under water; as it was considered that the extreme slowness with which this concrete set gave ample time for the thorough slaking of the cement before setting.

The sand used was almost entirely obtained by the crushing of sandstone, quarried in the island, from beds containing a smaller quantity than usual of cementitious matter. This sand, although not clean, gave far better tests than sharp sea-sand, and only about ten per cent. less strength than the same crushed sandstone when thoroughly washed; the difference being so slight, the unwashed sand was used.

The concrete in the altars, backing, &c., was at first put in rather dry, and punned; but subsequently it was deposited in thinner layers, with a greater quantity of water, and trampled down. A more water-tight concrete was thus obtained. The sandstone, too, being not very hard, was apt to break up under punning, thus leaving weak spots in the concrete.

(Paper No. 2537.)

"The Alexandra Graving-Dock, Belfast."

By William Redfern Kelly, M. Inst. C.E.

In 1882 the Commissioners of the Port and Harbour of Belfast obtained powers to execute extensive dock and harbour works, and to raise a loan of nearly £1,000,000 for that purpose. Among the works authorized by the Act was a large graving-dock and other works on the Co. Down side of the harbour, partly on land reclaimed from the sea, and partly in the waterway of the Victoria Channel, south of East Twin Island. For many years previously, a want of dry-dock accommodation was seriously felt, not only for the repairs of the many large vessels which trade to and from Belfast, but also to afford proper facilities and encouragement to the ship-building trade, which has assumed great importance there in recent years. 8,800 hands are employed in the Belfast ship-building and engineering works; and some of the finest ships in the mercantile marine have been built and engined at the port.[1] The graving-dock accommodation at Belfast, prior to the construction of the Alexandra Dock, consisted of two small docks on the west side of the Clarendon Dock, and a larger one near the north-east corner of the Abercorn Basin, the dimensions of which are given in Appendix I.

The first sod of the Alexandra Graving-Dock was cut on the 24th of April, 1885, by H.R.H. The Princess of Wales; and it was formally declared open by H.R.H. Prince Albert Victor of Wales, on the 21st of May, 1889, when the "Teutonic," of the White Star Line, was docked. The works comprise a large graving-dock and entrance-basin; two timber jetty-quays; pump-wells; engines, pumping-machinery, and buildings; and a fixed derrick-crane capable of lifting 100 tons, together with some minor works (Fig. 1, Plate 4).

[1] In the year of the opening of the new graving-dock, the tonnage of the vessels launched at Belfast reached 79,853 tons; of which 56,430 tons came from the yard of Messrs. Harland and Wolff, who employ 6,000 hands, and whose ship-building and engineering works cover 52 acres of land.

Cofferdam. — A large portion of the site of the graving-dock had been reclaimed from the sea by the deposit of material raised by dredging, during the past twenty years, from various parts of the River Lagan and harbour. Alternate layers of sand and clay beds, yellow sand, estuarine clay and grey sand, underlay the dredged deposit; and, at about 19 feet below low-water level, a thin layer of peat was met with, below which, after passing through strata of grey and red sand, boulder-clay was encountered. In the red sand, overlying this boulder-clay, the dock side-walls and floor were founded, at a depth of 39 to 41 feet below the present coping-level. A considerable portion of the site of the north end of the dock, and of the entrance basin, extended into the tideway, and therefore a cofferdam had to be formed on the foreshore, opposite to the entrance-basin, to enable almost all the concrete and masonry, and some of the timber jetty-quay works to be executed in the dry. As a large portion of the foreshore was at a fairly high level, a broad clay stank was constructed in the line of the dam, by tipping from wagons the stiff blue estuarine clay from the dock excavations. Where the escarpment was steep, and the water deep in the line selected, and where the side slopes of an earthen dam would have unduly encroached upon the waterway of the Victoria Channel, a timber dam was formed; partly of 12-inch baulks placed in a single line, securely bound together and caulked at the joints; and the remainder, where the water-pressure was the greatest, of two rows of sheet piling, a system which was subsequently used in other portions of the permanent works. The space between the two rows of piles was filled with the blue clay, locally termed "sleetch," which requires no puddling or manipulation of any kind.

Excavations.—The specification provided that the excavation should be made with side slopes of 4 to 1, from the surface to datum-level (3 feet above ordnance datum), below which, where the earth was stiffer and more consolidated, the slopes were to be 3 to 1. The contractors were, however, permitted to adopt the more economical trench system instead (Fig. 2). Along both sides of the cutting, horizontal walings, 12 inches square, were placed 4 feet apart, and were kept at their proper distances, laterally, by means of 12-inch square timber struts, extending across the trench, placed 8 feet apart. In each cutting, which was 30 feet in depth, there were seven tiers of these struts. Behind the walings, short poling-boards, 4 feet long, 1 foot wide, and 1 to 2 inches thick, were placed close together; the lower portion of the cutting being faced with 3-inch

sheet piling to prevent the sides from falling. The average width of this trench was 22 feet between the walings. The excavated material was lifted in iron buckets, by light steam-cranes travelling on rails along one side of the cutting. It was removed by tramway-wagons to a distance not exceeding 1,000 yards, as the best portions were required for backing behind the dock-walls, and the remainder for making up ground for proposed ship-building premises in the immediate vicinity of the new dockyard. The system of timbering the sides of earthwork trenches with poling-boards, struts and walings, is not altogether satisfactory where the cutting has to be as deep as was the case here, more especially when the material in the lower portions of the cutting is sand fully charged with water. In several instances the poling-boards gave way, or became displaced through uneven settlement, or excessive pressure of the superincumbent earth-work. Earthy matter in such cases finds its way into the pores of the concrete, and no amount of washing can thoroughly remove it. Strong strutted sheet-piling, though somewhat more expensive, constitutes a much safer protection against the slipping-in of the sides of deep trenches. Whilst excavating the lower portions, at about 24 feet below average low-water level, some heavy springs were encountered in the sandy stratum. These springs, "blows" or "boils," occasioned much trouble in getting in the foundation layer of concrete in many parts of the dock; some of them were of considerable volume, and so "quickened" the sand as to cause much uneasiness for the safety of the side-timbering of the trenches. By judicious treatment, however, the action of the water was confined within certain limits, and directed by distributing-channels so as to relieve the pressure on the foundation, where it emerged most strongly, until the lowest concrete layer had been deposited and had set firmly. Thus the springs, being driven forward and circumscribed, were mastered so successfully that the original plans of the dock were adhered to.

Graving-Dock and Entrance-Basin Walls.—The dock is 800 feet in length along the floor to the centre of the outer caisson-groove, and 850 feet from the face of the apron of the outer sill to the back of the wall at the south end of the dock (Fig. 1, Plate 4). Its width, between the lower plats of the side altars, is 50 feet; and its width at the top is 92 feet, and 98 feet from back to back of the side walls (Figs. 3, 4, and 5). The depth of the dock is 31 feet from the coping to the sill and floor-level. At ordinary low-water level, there is a depth of 17 feet of water on the

sill, and at ordinary high-water level a depth of 25 feet.[1] The width of the entrance, at the coping level, is 80 feet (Fig. 3). The dock is divided into three sections, the outer of which is 300 feet long, the next 200 feet, and the inner 300 feet; and between each there is an entrance-sill with a caisson-groove, so that with three caissons the dock could be divided into three separate compartments of 300, 200, and 300 feet respectively (Fig. 1). At a shipbuilding port like Belfast, such an arrangement is especially valuable, as a vessel may require to remain in the inner section for two or three months, for being lengthened, or for some important overhaul; and, during that time, the outer compartment would be available for vessels only requiring docking for a shorter period. The dock-floor is level in the centre, from one end to the other; but it falls 6 inches from the centre-line, on either side, towards a water-channel, 12 inches by 12 inches, which is carried completely round the floor and conveys leakage from the dock to the pump-wells. The dock-floor and sills are at the same level, so that the keel-blocks may be set on both to suit any length of vessel up to about 800 feet.

A well, 12 feet in diameter and about 20 feet deep, has been constructed below the level of the floor at the north end of the dock, Fig. 4; and is covered with greenheart planking laid on a wrought-iron movable beam. This well will be very serviceable when the rudder of a vessel has to be removed; and, although such occasions do not occur frequently, provision for them is expedient in large graving-docks. About 176 portable sliding wedge-shaped keel-blocks are placed along the centre-line of the dock, $4\frac{1}{2}$ feet apart; they are made of cast-iron and are about $2\frac{1}{4}$ feet high, their tops being fitted with heavy greenheart caps which form the seats for the vessel's keel. The altars are shown in Fig. 4; the upper six are each 3 feet in height, which is rather too great to allow of easy access from one to another; but twenty sets of smaller steps of granite are placed round the dock at convenient distances. 7 main stair-ways are also provided (Figs. 1 and 3), each having a series of steps on either side of an inclined plane of granite, which serves for raising and lowering materials, tools, &c. The stairs are so recessed that the coping extends in an unbroken line round the top of the dock; and a wall, 33 inches high, is formed round three sides of

[1] H. W. O. S. T., 10 feet 5 inches; H. W. O. N. T., 9 feet 8 inches; L. W. O. S. T., 1 foot 7 inches; L. W. O. N. T., 2 feet 4 inches; highest recorded tide, 14 feet 11 inches, above the harbour datum.

the stair-way for the protection of persons frequenting the place. A concrete quay-wall has been built on the west side of the entrance basin, and for a short distance along the Victoria Channel (Figs. 1 and 6). The lower concrete[1] of this wall was deposited in the tideway, between two rows of 12-inch sheet-piles, from iron skips with hinged doors. A return-wall has been built on both sides of the outer entrance of the graving-dock, as indicated in Fig. 1; a section of this wall, built inside the cofferdam, is shown in Fig. 7. The graving-dock side-walls and floor, and the return-walls of the entrance basin, and the upper part of the west quay-wall, were constructed of concrete *in situ*; the hearting being of No. 2 concrete, and the facework of No. 1 concrete.[2] The coping-stones, the caisson-groove stones, side-quoins, invert-sills, and the entrance side-walls, up to ordinary low-water mark, are built of granite. The surface of the quoins is finely worked, for a depth of 21 inches from the face, so as to form perfectly water-tight joints with the keels and stems of the caissons. The face-work, to a depth of 9 inches, of the altars and stairs of the dock, the side-walls of the entrances, the return-walls at the outer entrance, and the west quay-wall of the entrance-basin is composed of No. 1 concrete, set in moulds and smoothly finished on the surface.

Culverts.—There is an inlet-culvert at each side of the outer entrance of the graving-dock, 5 feet by 4 feet on the west side, and 7 feet by 5 feet on the east side; and similar culverts, 5 feet by 4 feet, are formed in the side-walls of the inner entrances. All these inlets have oval granite cut-waters at their mouths. An outlet-culvert, 7 feet by 5 feet, along the east side, connects each compartment of the dock with the inlet-well; and the discharge-culvert, 7 feet by 6 feet, runs from the discharge-well at the pumping-station, to the east return-wall of the entrance-basin. These culverts are formed of concrete, the arched crowns and inverts being of brick-work, in three $4\frac{1}{2}$-inch rings, and the side-walls of finely finished No. 1 concrete facing. The penstock chambers are of granite; the faces and jambs of the paddle grooves being polished. The wedge-shaped double-faced paddles, which close the culverts, are made of greenheart, and are raised and lowered by vertical screw spindles

[1] One part of Portland cement to 2 of sand, and $1\frac{1}{2}$ each of gravel and whinstone metal.

[2] No. 1. One part of Portland cement to 3 of fine gravel and 1 of sharp sand. No. 2. One part of Portland cement to 2 of sharp sand, $2\frac{1}{2}$ of whinstone metal, and $3\frac{1}{2}$ of coarse gravel (Appendix IV).

worked by manual labour. Each penstock-chamber is fitted with two paddles, which are suspended from a top cross-framing, bored and fitted with two brass bushes, with a cast-iron cross-head and cover-plate, fender, stays, and cross-plate, together with two pitch-pine connecting-rods. Each of these sluice-gates, complete, cost about £150.

Pumping-station.—This is situated near the outer entrance of the graving-dock, and contains a receiving chamber, 21 feet by 13 feet, by 17 feet high at the centre, into which the water flows through an inlet-culvert, 7 feet by 6 feet. Thence it passes into two circular wells, 14 feet in diameter, in which the main pumps are fixed, Fig. 8. From these it is forced into a discharge well, 21 feet by 7 feet, and thence finds a way through an outlet-culvert, 7 feet by 6 feet, into the entrance-basin. The main side-walls of these wells are composed of concrete and brick-work; the lower portions, both the facing of the side-walls and the well-seats, being constructed of granite ashlar. The arched roof of the receiving-chamber and face-work of the pump-wells are built of machine-made brick-work, set in Portland cement mortar. On the upper walls of these wells the sandstone foundation-blocks are set, upon which the pumping-engines are fixed. There is a boiler-house adjoining the engine- and pump-room, constructed to contain four large boilers, and a fuel-economizer, Fig. 8; and in addition to these are a copper- and lead-store, a coal-store and a sail-loft. The chimney, 120 feet in height, is founded upon 49 bearing-piles, 32 feet in length, surmounted by a bed of concrete, 21 feet by 21 feet by 6 feet.

Pumping-machinery.—The engines, pumps, and machinery were so designed that 10,000,000 gallons of water could be discharged from the graving-dock into the entrance basin within 2½ hours. There are two pairs of horizontal compound non-condensing steam-engines, of 500 HP. combined, having their cylinders placed at right-angles, each pair acting directly on one crank-shaft with sweep cranks, for working with a steam-pressure of 80 lbs. per square inch. The high-pressure cylinders are 20 inches, and the low-pressure cylinders 31 inches in diameter, the stroke in both cases being 24 inches. Expansion-valves, variable by hand, are provided for the high-pressure cylinders, and a single slide-valve for the low-pressure cylinders. These engines are fixed upon box-girder frames of cast-iron, specially prepared for carrying the crank-shafts, with phosphor-bronze steps, having vertical and horizontal adjustments. The crank-shafts are of forged steel, prepared for coupling to the pump-shafts. The connecting-rods are

of wrought-iron, fitted with phosphor-bronze steps and adjustments. Steam-jacketed receivers, equipped with safety-valves and siphon drain-pipes, are fixed between the cylinders; and high-speed governors, with connections to throttle-valves, are provided. The engines are placed on foundations at the floor-level, close to the two large pump-wells, into which the cast-iron box-girders are fixed. The wells and arrangement of pumping-gear are shown in section in Fig. 8. At the bottom of the wells are fixed two cast-iron centrifugal pumps 7 feet in diameter. The engines are so designed that either or both pumps may be worked at the same time.

A centrifugal pump, 9 inches in diameter, is fixed in the leakage-well, and is driven by belting from a horizontal non-condensing oscillating steam-engine, having a 10-inch cylinder with a 15-inch stroke. The steam is taken from three cylindrical boilers, each 30 feet in length and $7\frac{1}{2}$ feet in diameter, with two flues, 3 feet tapering to $2\frac{1}{2}$ feet, in diameter. The shell of the boilers is of $\frac{7}{16}$-inch annealed steel plate, and the ends are $\frac{9}{16}$ inch in thickness. The working pressure is 80 lbs. per square inch, the test pressure being 140 lbs. per square inch. A fuel-economizer, having 256 vertical 4-inch pipes, heats the feed-water, the scraper-gear being driven by a belt from a small horizontal engine.

East and West Jetty-Quays.—Along the east side of the entrance- and launching-basins, west of the graving-dock, two timber jetty-quays have been erected, the former 510 feet long and the latter 840 feet. Eight jetties, connected by a narrow wharf, extend 70 feet back from the quay face (Figs. 1 and 9). The jetties are 20 feet, and the wharf 15 feet wide. All the timber-work is of pitch-pine except the fenders, which are of American rock-elm. The coping-timber is protected by a sheathing of malleable iron, $2\frac{1}{2}$ feet broad and $\frac{1}{4}$ inch thick. The pitch-pine was creosoted with 4 lbs. of creosote per cubic foot, which, owing to the density of the timber, was with difficulty forced into it. Twenty-five mooring-bollard piles, 48 feet long, were driven and secured to the main framing of the jetties and quays, and fitted on the top with cast-iron bollard caps. The bays of piling of the jetties are 9 feet apart, and of the quays between the jetties 8 feet. The slopes behind the jetty-quays down to the lowest low-water mark, are protected with 16-inch rubble whinstone pitching, laid on a 6-inch bed of gravel.

A quay-wall, 80 feet in length, and three piers and foundations for supporting the 100-ton derrick crane, on the west quay, were constructed of concrete in the tide-way, within two rows of sheeting-

piles 38 feet long. The three crane-piers are raised 22 feet above the quay level; they are 20 feet by 20 feet at the base, and 17½ feet by 17½ feet at the top, and have wrought-iron holding-down bolts. Plate castings are built into the piers for securing the granite seats and the foundation castings of the crane. Along both sides of the derrick-crane seat, a timber wharf, very economical and serviceable in form where the depth of water in front of the quay is not greater than about 10 feet at ordinary low-water, was constructed for a total length of 220 feet. Forty-five bays of supporting-piles in front, and stay-piles, four in each bay, behind, were driven 5 feet apart along the wharf. A row of sheeting-piles, 22 feet long and 7 inches thick, was driven along the face of the wharf. For a depth of 14 feet below the coping-level, close 4-inch planking was spiked to the back of the front row of supporting piles; and a coping-timber, 18 inches by 10 inches, was secured along the quay face to the pile-heads. The wharfing was tied back by iron bolts to the stay-piles; and the space immediately behind the face-work was filled in with ashes, brick rubbish, &c.[1]

Caissons.—Two ship-caissons, which will both fit any one of the three caisson-grooves, have been provided for closing the dock, so that it may be partitioned off into two divisions of 500 feet and 300 feet in length respectively (Fig. 10, Plate 4). The hull is of wrought-iron, framed and braced together. There are four decks, the three lower of which are open lattice-work connecting the deck stringer-plates of both sides. The keel- and stem-plates are 2¼ inches thick, and the keel-base is formed of two angle-irons riveted in the wake of the garboard strakes. On both sides of the keel and stems heavy pieces of greenheart are bedded on and bolted to the ironwork, the timber on both sides of the keel and stems being planed true to fit the polished masonry faces of the grooves, with which they form a thoroughly water-tight joint. The frames of the caisson are of iron angle-bar; below the level of deck B they are spaced at distances apart of 3 feet. The deck-beams are of iron angle-bar. The skin-plating ranges in thickness from ⅜ inch at the upper part to ⅝ inch at the lower part of the caisson. The large plates are laid with their greatest lengths horizontal, in alternate inside and outside strakes, with vertical butt-joints. Between decks A and B, in the centre of the caisson, is a room with water-tight floor and bulkheads, in which the engine, boiler and pumping-machinery are placed. Hatchways in the upper deck give access to the engine-

[1] The cost of such a wharf-facing amounts to between £10 and £12 per lineal foot of frontage.

room and other parts of the interior of the caisson. The roadway-deck has strong deck-beams and stringers of iron angle-bar, and it is cleaded with 4-inch Dantzic oak planking, caulked, and payed with marine glue. A horse-track along the centre of the roadway is formed of American rock-elm slabs spiked to the deck flat; and, on each side of it, tracks of wrought-iron $\frac{1}{2}$-inch bars are screwed down to the decking; guides of angle-bar are fitted along their outsides; and a hinged hand-rail of wrought-iron gas-pipe is fixed along both sides of the roadway.

Capstans.—8 capstans are fixed round the graving-dock on the east side of the entrance, one being driven by steam and the others by hand. The steam-capstan can work with double and single power, both by hand and by steam. The others are 5-ton, single- and double-geared hand capstans with vertically-grooved barrels, steel gearing, and brass bushes. They are placed on the west side of the outer, and on both sides of the two inner entrances, and at the south end of the dock. There are 64 cast-iron bollards, fixed at intervals of about 50 feet along the dock and quays.

100-*Ton Derrick Crane.*—This crane is capable of lifting 100 tons at a radius of 50 feet, 80 tons at a radius of 60 feet, and 60 tons at a radius of 70 feet. It is used for the shipment of heavy machinery and boilers, and for masting purposes, and is one of the largest of the derrick type in the kingdom. Steel predominates throughout the structure, including the gearing, which is chiefly enclosed between the cheeks of the mast. The mast works in a massive centre step, resting on concrete, in which is fixed a steel pivot, 15 inches in diameter, bearing upon disks of steel and phosphor-bronze. The pivot is held in its place by a bottom girder fixed at the base of the mast; and it also receives the steps of the jib. At the top of the mast a strong tee-shaped pin, of mild steel, 15 inches in diameter, is cottered down to a casting fixed to the framing, and to this pin the slewing-straps, containing the pulleys for the wire ropes which regulate the range of the jib, are secured. The combined stress due to the jib suspension and load is borne by this pin, and is opposed by the resistance due to the back-stays. The stays are single, on the box principle; so also is the diagonal stay between the lower portions of the back legs. The feet of the back-stays are held down by cottered steel bolts. They are in two lengths, with intermediate castings to allow of expansion and contraction. The jib is double, and has two steel cap-pulleys for loads up to 26 tons, and four pulleys for

the main load up to 100 tons. It is raised and lowered by an engine with double 12-inch cylinders having a 16-inch stroke, with link reversing-motion, working direct on a worm-wheel 8 feet $5\frac{3}{8}$ inches diameter by $8\frac{1}{2}$ inches broad and $3\frac{1}{4}$ inches pitch. The steel pulleys, 5 feet in diameter, are split at the bosses, and are bushed with gunmetal. The main block has three similar pulleys, the hook or sling working on a series of conical friction-rollers for easy turning. The hoisting-engines have also double cylinders and link reversing-motion like the luffing-engines. The steel-wire rope is 7 inches in circumference, and has 6 strands, each proved with a load of over 30 tons. The barrel has three separate ropes; one for light loads, which hangs beyond the main load and is double; one for the main load, 7 fall; and the third for luffing the jib, 8 fall. They are wound separately on three barrels spirally grooved. Revolution is effected by a pair of cylinders, 8 inches in diameter, with a 12-inch stroke. There is a link reversing-motion with two pinions, one on each side, working into a steel rack. All the engines are under the control of one man, and are protected from the weather by a glazed enclosure. The boiler is of mild steel, $6\frac{1}{2}$ feet in diameter and 14 feet high, and has 9 cross-tubes. It was tested to 160 lbs. to the square inch. The feeding is effected by a donkey-engine. The total weight of material used in the construction of this crane is 220 tons; the minimum factor of safety being considerably over 6 to 1, and that for the flexible wire rope over 10 to 1. The bottom of the main lifting-block gives a clear hoist of 90 feet; the jib is 100 feet long, and admits of a range between 30 and 80 feet, with a large amount of swinging movement within the limits of the back-stays; rendering the crane capable of lifting its heaviest working load from the quay, and depositing it in a vessel with great nicety.

Tramways.—To connect the graving dockyard with the tramways on the Co. Down side of the river, a single line of rails has been laid along the Queen's Road, from the Abercorn Basin, by the west side of the graving-dock; and a siding from this line passes under the 100-ton derrick crane (Fig. 1). The total cost of the works was £148,983, details of which, together with a schedule of prices, are given in Appendix IV.

Concluding Remarks.—Shortly after the completion of the works, it was observed that in several parts of the facing of the altars fine cracks began to appear; these gradually became wider, and water, highly charged with saline matter, exuded from them; the quantity, however, was small at first. The flow subsequently

increased considerably in some places; and was followed by a bursting and disintegrating action of the facework of the altars in many parts of the dock, notably below the level of ordinary low water. The floor of the dock also began to show symptoms of disruption, especially at the joints, where fresh concrete had been united with portions previously laid and set; but in many cases the cracks appeared independently of those joints, notwithstanding the thickness of the floor, which was 10 feet in the centre. The water flowed in considerable quantity through some of the fissures, and, in several instances, carried with it fine sand; thus indicating that the floor had yielded through its entire thickness, owing to the hydrostatic pressure acting under the foundation, and to the weakening, through disintegration and decay, of the concrete. In June, 1890, the disruptive symptoms continuing to develop, Messrs. Hawkshaw and Hayter were requested by the Belfast Harbour Commissioners to examine the works and to report thereon. Mr. Harrison Hayter accordingly visited Belfast, and having made a careful inspection of the graving-dock, a report was presented by the firm, in which the following conclusions were expressed:—(1) That the disintegration was mainly due to the presence of magnesia in large quantities in the work. (2) That this substance was conveyed to the site of its destructive operations by sea-water, which was continually percolating the concrete, and which found its way from the adjacent tidal river through the sandy backing and the strata overlying the boulder clay; the upper surface of which latter formation was assumed to be some 3 or 4 feet below the lowest portion of the concrete of the side-walls of the graving-dock. (3) That the magnesia abstracted, in an altered form, the lime from the Portland cement contained in the concrete. (4) That the affinity of magnesia for water was so great that "two parts by weight of magnesia, in becoming hydrated, will take up and solidify one part of water." (5) That this chemical action would naturally lead to the deterioration and disintegration of concrete under such conditions as existed in the Alexandra graving-dock.

The remedies suggested by Messrs. Hawkshaw and Hayter were as follows:—1. The cutting away of all the defective concrete of the side-walls and floor, and replacing it by a superior rich Portland cement concrete, so as to render the work as impervious as possible, and thus to prevent the continuous influx of sea-water, which carried with it a continuous supply of that base which is found to be so powerfully destructive an agent in marine concrete

works. 2. Failing the satisfactory solution of the difficulty by the above means, that the works should be isolated by an impermeable wall of clay puddle built round the dock; the upper portion of which should be at least higher than the maximum high-water level; and the base of which should be carried down into the boulder-clay formation, which, it was anticipated, might be found at a depth of a few feet below the dock foundation. Steps were taken to give effect to these suggestions; and it is hoped that the results may be satisfactory.

The engineer of the works was Mr. Thomas R. Salmond, M. Inst. C.E., Engineer-in-Chief to the Belfast Harbour Commissioners; and the detail-drawings, specifications, quantities and estimates were prepared by the Author, who is Chief Assistant Engineer to the Corporation. The various works were, with the exception of the pumping-engines and machinery, executed by local contractors. The principal inspector of works for the Harbour Commissioners, on the graving-dock and jetty contracts, was Mr. John Powell.

The Paper is accompanied by drawings from which Plate 4 has been prepared.

APPENDIX I

Dimensions of Old Graving-Docks.

Year Opened.	Name of Dock.	Extreme Length.	Width at Entrance.	Width at Floor Level.	Width at Coping Level.	Depth of Sill at Ordinary High-Water Level.	Relation of Sill to Bottom of Dock.	Observations.
		Feet. Ins.	Feet. Ins.	Feet. Ins.	Feet. Ins.	Feet. Ins.		
1800	Clarendon graving-dock, No. 1 .	252 6	30 0	27 6	50 0	8 3	Level	Leaf gates on hinges.
1826	Clarendon graving-dock, No. 2 .	299 0	36 0	34 0	58 0	10 3	Ft. Ins. 0 6 above floor	Ditto.
1867	Hamilton graving-dock .	470 0	60 0	50 0	84 6	15 10	2 2 above floor	Caisson gate.

APPENDIX II.

Quantities of some of the Principal items of Labour and Materials.

Excavation	286,000 cubic yards.
No. 1 concrete	4,100 „ „
No. 2 concrete	57,000 „ „
Granite work	71,000 cubic feet.
Stone pitching	6,400 superficial yards.
Brick-work in Portland cement mortar .	4,000 cubic yards.
Timber, principally pitch-pine	78,600 cubic feet.

APPENDIX III.

PORTLAND CEMENT SPECIFICATION AND DETAILS RELATING TO THE CONCRETE.

All Portland cement used for this contract shall be subjected to the following tests, and must fulfil all the following requirements:—

1. It must be uniform in colour and composition.

2. Its weight, when cool and lightly filled, shall be not less than 112 lbs. per striked imperial bushel.

3. It shall be ground so finely that at least 90 per cent. of its bulk shall pass through a sieve gauged to 2,500 meshes per square inch, the residue being of an ordinary character.

4. Briquettes shall be formed from each consignment of cement received on the works. These briquettes shall be made by whomsoever the engineer may direct, and, after being made, they shall, as soon as the cement has set in the moulds sufficiently well to hold together without losing shape or form, be immersed in water for a period of seven days, at the expiration of which time they must be capable of sustaining a tensile stress of at least 350 lbs. to each square inch. The tests shall be made by the engineer, or by any person appointed by him for that purpose, and with the Commissioners' own testing machine.[1]

5. The engineer shall have power to reject any cement, provided that he finds, on making further tests for longer periods than seven days, that it is, in his opinion, unsatisfactory for the work. For the purpose of instituting the foregoing, or other tests, the contractor shall allow from time to time every facility for selection from the cement stored on the ground to the engineer, or to any person whom he may direct to make such selection. No cement will be allowed to be used for any portion of this contract unless, in the opinion of the engineer, or his inspector, it has been properly shot and cooled; and no cement failing to satisfy all the foregoing requirements shall be allowed to remain on the works for a longer period than seven days from the date of the order for its removal.

The coarse gravel and broken stones were specified to be not larger than would pass through a 3-inch ring, the fine gravel not larger than would pass through a $\frac{3}{4}$-inch ring, and the sand to be good, clean, sharp, fresh-water sand. All the mortar used in the work was composed of 1 of Portland cement to 2 of sand. A modified form of the Stoney concrete-mixer driven by steam-power was used for making the concrete. It consisted of an open trough of sheet-iron, with a shaft passing through its axis; and several blades were bolted on this shaft, projecting at right-angles, which, in revolving, mixed the concrete. Water was allowed to flow gently on the concrete ingredients in the trough from a pipe pierced with numerous small holes placed above the shaft.

[1] A Michele machine.

APPENDIX IV.

Cost of Works.

Work.	Cost.	Observations.
	£.	
Alexandra graving-dock and pumping-station up to ground line	74,492	Graving-dock proper.
Dredging work not included in dock contract	4,295	,, ,,
Paving of graving dockyard	2,806	,, ,,
Gas and water mains, and lamps . . .	1,362	,, ,,
Penstock-doors, or paddles, fourteen in number	2,000	,, ,,
Eight capstans, one steam and seven manual	503	,, ,,
Tramway in graving dockyard	900	,, ,,
Two caisson gates	8,759	,, ,,
176 cast-iron keel-blocks	918	,, ,,
Engine- and boiler-house, store buildings, chimney, &c.	5,040	,, ,,
Engines and pumping-machinery, boilers, cisterns, &c.	5,390	,, ,,
Enclosure-fencing	313	,, ,,
Working-shed for tradesmen employed at the dock	515	,, ,,
Latrine	81	,, ,,
East jetty-quay, entrance-basin	7,477	Entrance-basin and dock-approaches.
West quay-wall of entrance-basin, and spur return-wall; and jetty to connect pier-head with west jetty-quay	6,245	,, ,,
West jetty-quay, Victoria Channel . . .	10,299	West jetty quay for engining, masting, and fitting out vessels.
Seat for 100-ton derrick crane	7,596	,, ,,
One hundred-ton derrick crane	5,970	,, ,,
Two trucks for ,, ,, ...	164	,, ,,
Wharfage at each side of crane seat, behind west jetty-quay	2,096	,, ,,
Tramway on Queen's Road	1,762	Railway connection between graving-dock and existing lines of quay tramways.
Total . . . . . £	148,983	

SCHEDULE OF PRICES.

	s.	*d.*	
Excavation, ordinary, and running to spoil, and re-filling behind walls	1	1	per cubic yard.
Submarine excavation	5	0	„ „
Paving of river-slopes, hand-pitching	6	0	per superficial yard
No. 1 concrete for face-work	20	0	per cubic yard.
No. 2 concrete	13	0	„ „
Brickwork, in Portland cement mortar	25	0	„ „
Granite, in coping	4	6	per cubic foot.
„ in entrance-sills and side-walls	5	0	„ „
„ in caisson-grooves	5	4	„ „
„ in penstocks	5	6	„ „
„ in culvert work, cut-waters, slides, and small steps on altar courses	4	6	„ „
„ in pumping-station work, well-seats, &c.	5	0	„ „
Pitch-pine timber in supporting piles	3	0	„ „
„ „ in sheeting piles	3	6	„ „
„ „ in joists, braces, and walings	3	6	„ „
„ „ in coping	3	6	„ „
„ „ in surface-planking, 6-inch	13	6	„ „
American rock-elm fenders	4	6	„ „
Wrought-iron coping-sheathing	6	3	per lineal foot.
Screw-bolts and spikes (average)	2	0	each.
Pile-shoes, cast-iron tips, wrought-iron straps	0	1½	per lb.
Cast-iron keel-blocks	5	0	per cwt.

(*Paper No. 2496.*)

"Construction of a Concrete Graving-Dock at Newport, Mon."

By Robert Pickwell, Assoc. M. Inst. C.E.

As graving-docks built of concrete in difficult ground are comparatively uncommon, an account of the construction of the Mary Dock at Newport, Mon., may be interesting to the Institution.

The dock was built of cement concrete throughout, with the exception of the hollow quoins and the sills, which were of Cornish granite. The length is 350 feet on the floor-level from the head to the mitre of the outer gates, the breadth on the floor is 50 feet, the depth from coping to sill-level is 30½ feet, and from coping to floor 31½ feet, and the top width is 72 feet (Fig. 1, Plate 5). The keel-blocks are spaced every 6 feet along the centre; there is one set of steps and a timber-slide about midway on the north side, and iron step-ladders are fixed at short intervals. The dock is capable of taking in the largest steamers that can navigate the river Usk; and the depth of water over the sill and blocks at high water is 21⅔ feet at spring tides, and 13⅔ feet at neap tides.

The contract was let to Mr. John Mackay, of Hereford; work was commenced on the 1st January, 1889; and the dock was completed in September, 1890, at a cost of about £25,000.

As the space available was limited, the Author specified that the side-walls should be first built within timbered trenches, and that the "dumpling," or centre earthwork, should be then excavated and the bottom constructed; Figs. 2 and 3 exhibit this method of construction. Borings showed that the foundations would be in fairly good brown clay and silt, not liable to run to slurry on exposure to water, but, nevertheless, requiring careful treatment; and that from 4 to 6 feet below the base of the walls there was a bed of running greensand, about 4 feet thick, fully charged with water; whilst 15 feet below the base of the walls gravel was found (Figs. 4, 5, and 6). Owing to the treacherous nature of the foundations, and as almost half of the north wall had to be built outside the mud foreshore of Jack's Pill, the Author decided to drive 6-inch by 12-inch sheet-piling all round the site of the dock, at the back of the walls, so as to enclose it entirely.

Reclamation along the Foreshore of Jack's Pill.

A strong timber breastwork was first driven from U to V (Fig. 1, Plate 5), consisting of main piles, 12 inches to 13 inches square and 60 feet long, pitched 5 feet apart, with five rows of walings fixed on the outside; the spaces between the main piles, below the bottom waling, being filled in by sheet piles, 12 inches by 6 inches, and the upper part by 4-inch planking spiked to the back of the piles. The portions from V to W, and from W to X and Y to Z had to be made a permanent water-tight dam; that from V to W consisted of 13-inch piles 60 feet long, driven close together and caulked; and that from W round to X was formed by two close rows of 60-foot piles, 5 feet apart, the mud between which was taken out to a solid clay bottom, and the space filled in with clay puddle. The portion X Y was similarly constructed, in the form of a curve across the entrance, constituting the temporary dam, the piles of which were subsequently cut off at the apron-level. The whole dam was ultimately tied back to the walls of the dock by 2-inch tie-rods, 5 feet apart vertically and horizontally (Figs. 2 and 3); and as it was intended to keep out the water from the trenches of a large portion of the north wall, the work was pushed on at the outset. The foreshore of Jack's Pill to be reclaimed was a flat muddy slope, constantly slipping into the Pill, and gave great trouble in securing the pile-work. It was at first proposed to fill the whole space with earthwork from the dock excavations, and this filling was partly commenced near U; but it soon became evident that the pressure from behind was too great for the pile-work. It was then decided to clear the surface mud off the slope in flat steps, a few feet wide, down to the solid clay; and to cut deep cross trenches, 5 feet wide, and 10 feet apart, at right-angles to the slope, and fill them with steel slag, so that they should act as long counterforts. This plan also obviated the settlement of earthwork over the 2-inch tie-rods, which tended to bend them, and in some cases left cavities under them which caused serious leakage towards the back of the walls. The whole of this filling was consequently carried out in the manner described from U to W, the tie-rods being placed in the cross trenches, some of which extended 70 feet back from the pile-work. At every 20 feet, an excavation, about 12 feet square and 30 feet deep, was made at the back of the pile-work, and filled with hand-packed slag, so as to form a counterfort at the back of the piles. As the portion from W to X would be subjected to the thrust of both pairs of gates, the whole of the earthwork at

this part was taken out to a depth of 21 feet, and filled to the top with hand-packed slag; and subsequently the remaining space from U to W was filled with dry ashes—these expedients proving completely successful.

In order to prevent the water from obtaining access into the trench between W and X, a clay-puddle dam was thrown across from the double dam at W to T. In order to tie the double dam, until the wall was built from T to X, tie-piles were driven along the line of the back of the wall and tie-rods fixed into them. These piles were left in, and formed part of the sheet-piling at the back of the walls; and the rods were extended by Dutch cramps, and fixed into the wall as it was carried up. The bed of the Pill from U to the corner near X had ultimately to be dredged to a depth of 30 feet from the quay-level, to form a berth for large steamers; and 60-feet piles were used, partly on this account, and partly that they might reach the solid gravel. The temporary dam X Y, was perfectly effective; and, being curved, only required a couple of raking struts from the side-walls when the lock-pit floor was put in. On the removal of the temporary dam, the two ends were filled in by close piling, so as to keep the ends of the two permanent dams water-tight.

The Concrete Walls.

Excavation.—The trench for the side-walls was first of all sunk to the level of the top of the row of sheet-piling, 16 feet wide, and close timbered. The sheet-piling was then driven along the bottom of the trench with false leaders by an engine running along the top. After a convenient length was in position, the excavation was continued 16 feet lower, making a total depth of 36 to 38 feet, the permanent sheet-piling forming one side, and the temporary timbering the other. Temporary sidings were laid on the dumpling, for the travelling cranes and wagons to run on. When a sufficient length of trench had been excavated to the proper depth the concreting was commenced; and in no case was concrete allowed to be put upon wet ground, but about a foot of the bottom was left in, and only removed immediately before the concrete was deposited.

Concrete.—Owing to a difficulty in obtaining stone or gravel for making the concrete, the Author used broken steel slag, obtained from the Panteg Steel Works, delivered at 1*s.* 6*d.* per ton, being merely the cost of carriage. One ton was found to measure 26 cubic feet. The concrete consisted of 10 parts of this furnace

slag, broken up into pieces of $2\frac{1}{2}$ cubic inches, to 1 part of cement, the fine material resulting from the crushing taking the place of sand. To ascertain the shrinkage of the dry material after being deposited as concrete, the Author made the following trial. The materials were mixed dry in the following proportions:—$7\frac{1}{2}$ measures of broken slag, $2\frac{1}{2}$ of sand and 1 of cement, making 11 altogether, each measure containing 3 cubic feet. When these were made into concrete, they formed a block of 22 cubic feet. It would be interesting to compare this shrinkage in the concrete of one-third of the bulk of the dry materials with the experience of other engineers. An extract of the specification for the cement and concrete is given in Appendix II.

The first lot of concrete was put in near the lock-pit in the south wall, and up to the level of the dock floor, gauged as stated above; but as it did not appear satisfactory, it was subsequently made as follows:—A measure containing $1\frac{1}{5}$ cubic yard was filled with the broken slag as it left the crusher, and to this was added $\frac{1}{5}$ measure of sand and 3 cwts. of Portland cement. The whole was then passed through a horizontal mixer, and by means of iron trollies running on small tramways, laid over the trenches, was deposited through temporary shoots. This mixture, which consists of about 8 parts of the aggregate to 1 of the matrix, was used throughout the work, excepting for the face concrete, which was made as stated in the specification, Appendix II. The concrete was filled close up to the sheet piling at the back, and above that level close up to the side of the trench. The mass and skin of the concrete were brought up together, in layers of about a foot or 18 inches; they were kept separate, while being deposited, by a plank laid on edge, 10 inches from the moulds; this was then withdrawn, and the two concretes thoroughly trodden and worked together. The moulds were at first painted with soft soap; and brown soap was also tried in order to make them leave a good face on the work. This was found to be a failure, as the men, in using their shovels between the moulds and the concrete, worked the soap into the liquid material, which appeared to destroy its setting properties. After this, the moulds were thoroughly cleaned and covered with a thin coat of crude petroleum, which left a clean hard face. It was also found that a good face was left by having the moulds simply well cleaned. All exposed surfaces throughout the walls, bottom, chainways, &c., were made of this 6-to-1 concrete. To give additional strength to the dock-floor against both upward and downward pressure, second-hand ships' cables were laid across the walls 7 feet apart, at the level of the centre of the dock-floor;

and subsequently, when the dock-floor was put in, similar cables were stretched across, and shackled on to the short length in the walls, thus forming a chain bond across the floor and through the walls every 7 feet along the entire length of the dock (Fig. 4, Plate 5). The side-walls have stood remarkably well, and have shown no sign of settlement or movement.

The foundation for the lock-pit walls was very soft. Accordingly, in the south abutment-wall, which was constructed first, at about every 5 feet in height, a pair of cables about 4 feet apart were inserted, reaching from the outer end of the abutment-wall to about 80 feet along the inner dock-wall. Cables were similarly placed in the north abutment-wall. The abutment-walls were to have been built on the bottom, like the dock wall; and the south wall had been carried up, with its hollow quoins, to 16 feet above sill-level, when it was discovered that the quoins had settled $1\frac{1}{2}$ inch and the wall had gone about $\frac{3}{4}$ inch out of plumb. About this time the excavation was out for the north wall; and several blows occurred, bringing in much sand and water. The Author was afraid of sinking down to the gravel in search of a better foundation, lest the running sand should be drawn from under the existing walls, in contending with the water. Pumping was, consequently, stopped in this trench, and the water was allowed to rise to its natural level, in order to avoid any scour of sand from beneath; and the whole of this north wall foundation was piled, Fig. 5. The piles were placed about 4 feet apart from centre to centre, and were driven until they ceased to descend more than $\frac{1}{2}$ inch with a 12-foot blow from a 1-ton monkey. The water was then pumped out at neap tides, cross cap-sills fixed on, and the concrete deposited. Two rows of sheet piling were also driven across the trench close to the hollow quoins, and four piles were put under each of the heel-post stones, and the wall was built without any further difficulty.

In order to re-adjust the south wall, all the quoins were taken out, and about 5 feet in thickness of the face of the wall taken down; and, in the outer portion, the bottom of which only had been got in, openings were made in the concrete, and piles driven, as in the case of the north wall. Cross sills were placed on the piles, some of which extended across the bottom already in, and rested on the sheet piles at the back; whilst others were secured into the broken face of the higher piece of wall. The concrete was then replaced over the piles, bringing the wall up to its proper thickness. To secure a bond for this thick face, a dovetailed groove was cut about 4 feet square all the way down the existing concrete, and

filled in with new material. After this the wall was completed without further difficulty.

Dock Floor.

Excavation.—The dumpling (Fig. 3, Plate 5) was taken out, commencing at the head of the dock and working towards the entrance down to about 20 feet, thus leaving sufficient resistance at the base of the walls to prevent sliding. Being aware of the failure of similar work elsewhere, from the dumpling having been taken out too deep at once, the Author had a trench excavated to the proper level in the centre of the dock, only 15 feet wide, reaching from wall to wall, and the concrete put into place. Then a similar trench was taken out alongside the first one, and another length of floor, 15 feet wide, formed from wall to wall; and this operation was repeated until the whole of the floor was got into place without any mishap. Two rows of 13-inch piles were placed along the centre of the dock, 5 feet apart, and spaced longitudinally directly under the ship's blocks (Fig. 4); and they were driven until they sank $\frac{1}{2}$ inch with a 12-foot drop of a 1-ton monkey. They were driven in one cross trench, on one side of a length of floor already in place, whilst another trench on the other side was being excavated.

Concrete.—In putting in the concrete floor, the bases of the side-walls were cut away in the form of an inverted skewback, so as to afford a more secure joint for the floor. When half the thickness was in, the chain cables were stretched across from wall to wall, and shackled to the short lengths of cable projecting through the walls; and the upper half of the floor was then put in. These old chain cables were generally about $1\frac{1}{4}$ inch in diameter, and weighed about 85 lbs. per fathom. In putting in the lock-pit floor, a quantity of water boiled up near the north outer hollow quoins, and the contractor tried to stop the flow by the deposit of concrete at this place, which he weighted with a number of large granite sill-stones; but three tides after this, the water lifted the concrete and stones, and broke out with renewed energy. The foundations here have 5 or 6 feet of clay between them and the sand. This blow was cut off from the inside of the dock by two rows of sheet-piles, one under the line of the pointing sill, and another a few feet within (Fig. 6); the two rows forming a continuation of the sheet piling under the north wall. This sheet-piling prevented any danger of drawing the sand from under the walls; and accordingly, a concrete dam 6 feet thick, carried

down to the gravel, was placed across the lock-pit under the floor level, following the line of the outer pointing-sill. The rest of the lock-pit floor was put in without difficulty, close up to the temporary dam; and piles were put under the roller-path. At 4 places the floor was put in in the form of inverted arches, about 20 feet wide, making it there about 10 feet thick, thus forming additional struts to the toes of the walls. A 9-inch drain was formed below the bottom of the floor as the work proceeded, and ultimately extended throughout the length of the dock; and about midway a sump was formed, in which pumps were placed for dealing with the water. The drains and sump were kept open for some time after the dock floor had been completed, the portion of it extending from the outer to the inner sills having been filled with cement grout. Although during construction there was comparatively little water met with in the foundations, in spite of the work being entirely surrounded by sheet piling, a considerable quantity flowed over at the sump at the time of high water, showing that the bottom would be then subjected to up-lift. To ascertain the amount of this pressure, the bottom of the sump was filled with hand-packed stones, upon which a 9-inch stand-pipe was set, and the sump was then filled in with concrete, 6 feet thick; thus leaving the drain open throughout the entire length of the dock with the stand-pipe coming up to the dock bottom. A 9-feet stand-pipe was bolted on to this; and at spring tides, the head of water was just sufficient to flow quietly over the top; and, there being no scour, no sand was brought with the water. The stand-pipe was subsequently removed, and the pipe through the floor permanently stopped, by bolting on a water-tight cover; the object of this being that, in case of need, the suction-pipe of a pump could be at any time inserted, and the water taken from under the dock floor by pumping. The Author calculated the resistance of the dock floor as a beam resting on supports 48 feet apart, ignoring the advantage of the chain-bonding. Using the data given in the Paper on Portland Cement Concrete, and Mortar, by Mr. Charles Colson,[1] and taking 4 tons as the coefficient of strength, he found

[1] Minutes of Proceedings Inst. C.E., vol. liv. p. 270. This coefficient was obtained as follows:—A beam of 9 to 1 concrete twenty-eight days old, broke with a weight of 1·044 ton applied at the middle. The size of the beam was 1 foot 9 inches b 9 inches deep, by 3 feet 9 inches clear between supports.

$$\frac{(1\cdot75)\times(0\cdot75)^2\times C}{3\cdot75}=1\cdot044 \text{ ton.}$$

$$\therefore C=\frac{1\cdot044\times 3\cdot75}{(1\cdot75)\times(0\cdot75)^2}=\frac{3\cdot925}{0\cdot98}=4 \text{ tons.}$$

that the theoretical calculations were not borne out by experience in this case, because, according to the formulas, this section of dock bottom as a beam would only support itself at about 10 feet span; whereas the weaker parts of the dock bottom, which were only 5 feet thick, had resisted a head of water-pressure of about 9 feet over and above that necessary to counterbalance the dead weight; in other words, seeing that it was constantly being subjected to a head of water of over 20 feet, theoretically the invert ought to have blown up long ago, but it had not.

Gates.

The heel- and mitre-posts of the gates, 20 inches square, were of English oak, each in one piece. The rest of the framing was composed of pitch-pine, the beams being 22 inches by 14 inches each, consisting of two scantlings bolted together (Figs. 7 and 8, Plate 5). The planking consists of 7-inch by 3-inch pitch-pine, fastened with oak trenails, and caulked. The roller is fitted into a box with wedge adjustments. The dock is filled by means of a culvert, 3 feet in diameter, with inner and outer penstocks. As, however, it was found that the dock could only be filled through this culvert in one-hour-and-a-half during spring tides, two sluices were placed in the gates with openings of 3 feet by 1 foot. The rudder-well was sunk several feet deeper than was at first contemplated, after all the other work was finished; and in doing so the water-bearing stratum was again tapped. This water was shut off by first putting the bulk of the concrete into place, with the water standing in the well; and afterwards tubbing the water out with a wrought-iron boiler-plate casing, the space between the case and the concrete being grouted with neat cement. Stop-gates, of a similar construction to the main gates, closing against the inner sill, serve to retain 15 feet of water over the blocks in the dock.

Stability of the Walls.

Samples of concrete made according to the specification weighed 175 lbs. per cubic foot. In calculating the stability of the walls, he adopted the system described by Sir Benjamin Baker, Vice-President Inst. C.E., in his Paper on "The Actual Lateral Pressure of Earthwork,"[1] and designed them with a resistance equal to

[1] Minutes of Proceedings Inst. C.E., vol. lxv. p. 140.

a fluid-pressure of 71 lbs. per square foot. Sir Benjamin Baker states that he has found very few walls capable of supporting more than 22 lbs. fluid-pressure. The Author has had the walls carefully tested since their erection, and has found no movement whatever in them. Similar calculations gave 60½ lbs. equivalent fluid-pressure resistance for the walls of the Eastern Dry Dock, Newport, and 69 lbs. equivalent fluid-pressure for the walls of the Jarrow Graving-Dock, Newcastle, both of which the Author has had the opportunity of testing.

The Paper is illustrated by two drawings and four tracings, from which Plate 5 has been compiled.

APPENDIX I.

Prices of work.—The work was let as a lump-sum contract; but the following are some of the prices paid:—Pile-work, of Memel timber, from 2*s.* 4*d.* to 2*s.* 9*d.* per cubic foot driven complete, varying in price according to position; 2-inch wrought-iron tie-rods and couplings, £20 per ton fixed complete. Excavation within timbered trenches for dock walls, from 2*s.* to 2*s.* 3*d.* per cubic yard, down to 19 feet from top. Similar excavation in worst position, 3*s.* per cubic yard, increasing 3*d.* per cubic yard on the above prices for every 5 feet or part of 5 feet additional depth. Earthwork in excavation of dumpling, down to 19 feet, 1*s.* 9*d.* per cubic yard, increasing 3*d.* per cubic yard for every 5 feet or part of 5 feet in depth. Excavation of trenches in tide-way at back of piling, 5*s.* per cubic yard. Portland cement concrete, 10 to 1, 12*s.* and 12*s.* 6*d.* per cubic yard, including 10 inches of 6 to 1 skin to all exposed surfaces; and 8 to 1 concrete, 14*s.* 9*d.* per cubic yard, including the 6 to 1 skin.

The outer- and stop-gates contained 3,000 cubic feet of timber, and cost £1,450, including all ironwork, anchor-bolts, rollers, paths, &c., pumping, staff-expenses, and contingencies. Memel timber cost at the time about 1*s.* 4*d.* per cubic foot. Cement cost 31*s.* per ton.

Cost of hand-packed slag, 4*s.* 6*d.* per cubic yard; ashes for filling, 3*s.* per cubic yard.

APPENDIX II.

Cement: Weight and Fineness.—The whole of the cement to be of the best quality of Portland cement, weighing not less than 116 lbs. per striked imperial bushel, filled from a spout 18 inches above the measure and inclined at an angle of 45 degrees, finely ground, so that the residue, on a sieve of 2,500 meshes to the square inch, shall not exceed 20 per cent. by weight.

Storing cement.—The cement must be stored in the contractor's sacks until the testing is complete, when it is to be turned out in bulk, and stored for at least three weeks in a building with a wooden floor to be provided for the purpose.

Testing cement.—The cement must be of such strength that castings of neat cement, which have been immersed in water one day after being gauged, shall, at the end of seven days, bear a tensile stress of 700 lbs. on a section of $2\frac{1}{4}$ square inches. One sample out of every ten bags will be taken in each consignment; and any cement which does not stand the above test will be rejected, and must be forthwith removed. The cement must be re-bagged in sacks, each containing $2\frac{2}{3}$ cwt. of cement, which is the quantity required for each gauge-box mixing of $1\frac{1}{3}$ yard of material.

Concrete metal.—The material for the aggregate shall be steel or iron furnace-slag, and such broken stone as may be found on the site. All the metal must be passed through a Marsden or Blake breaker, and must be not larger than $2\frac{1}{2}$-inch cube, not screened from the small. The metal required for the face-concrete shall consist of the same material broken into $\frac{3}{4}$-inch cubes, and include the dust arising from the crushing. Sharp river-sand may also be used in the face concrete.

Concrete.—The whole of the concrete for the main walls and dock-bottom, &c., throughout, to consist of a measure of $1\frac{1}{2}$ cubic yard of broken metal, as above, and one bag containing $2\frac{2}{3}$ cwt. of Portland cement, and must be gauged as follows: a gauge-box, containing $1\frac{1}{3}$ cubic yard, must be filled with the metal, and one bag of $2\frac{2}{3}$ cwt. of Portland cement be added to it. It must be twice turned dry, and then watered through a rose, turning over the same material twice wet; or it may be mixed in a Messent mixer or other approved machine. The concrete to be at once tipped into and between the wooden shields, or mould-boards, fixed to the shape of the respective walls, &c., in layers not exceeding 2 feet in height at one time.

Face-concrete.—The face-concrete to be similarly mixed, but to consist of 4 parts metal and dust (2 parts of sharp sand), as follows: the gauge-box must contain $1\frac{1}{3}$ cubic yard, to have added to it two bags of cement of 2 cwt. each. This face concrete, throughout the work, to consist of a "skin," when finished, 10 inches thick on all exposed surfaces, and must be placed thus:—A plank, $1\frac{1}{2}$ inch thick, 12 feet long by 11 inches deep, is to be set at 10 inches from the face of the wall, with distance pieces. The common concrete is to be then placed in, from the plank to the back of the wall; whilst the face concrete is to be put in between the plank and the face-shields, or moulds. The face concrete is to be well worked with a shovel to the face, to secure solidity, and the plank then removed, and the whole well punned and trodden together. This facing must be worked to steps, copings, quoins, &c., throughout.

Shields or moulds.—The contractor must erect and secure the necessary moulds to the various walls, culverts, quoins, circulars, &c. The external surface or top of each layer must be cleaned and watered before receiving another layer of concrete. The moulds, if necessary, must be lined with jute, and painted over with a solution of common brown soap, boiled down until it assumes the consistency of ordinary oil-paint. All the necessary chain-ways, man-holes, culverts, &c., must be formed in the mass-concrete throughout.

Discussion.

Mr. Hayter. Mr. Harrison Hayter, President, said that the subject of graving-docks had not been before the Institution for some years, and it had now been presented in a very complete form, there being no fewer than 4 Papers by different authors, giving accounts of 4 kinds of graving-docks; so that, if there were anything to be said on the subject of graving-docks, they ought to form the basis of a good discussion. It was now his duty and pleasure (knowing what the result would be) to ask the members to thank the Authors for the practical and descriptive accounts they had given. Judging from precedent, it seemed to be to some extent recognized as a wise custom that Presidents should engage but little in discussion upon Papers. But his name and that of his partner had been mentioned in connection with the failure of the Portland cement concrete at the Alexandra Graving-Dock, Belfast, because the Harbour Commissioners had called upon them to advise what should be done under the circumstances. Accordingly, Mr. Hayter had paid two visits to Belfast and examined the Alexandra Graving-Dock, and he and his partner had made reports thereon. He would only briefly refer to the cause of the failure, because 6 years ago Papers were read on concrete as applied in the construction of harbours,[1] and last year Papers were read on Portland cement and Portland cement concrete,[2] and on both occasions in the course of the discussion the decay of Portland cement concrete under certain conditions was exhaustively dealt with. He would only, therefore, say that the cause of the failure was due to the salt water in its flux and reflux into and out of the porous concrete of the backing being therefore continually replenished, gradually (for the process was a very slow one) causing magnesian hydrate to form in the concrete, and abstracting, in an altered form, the lime from the Portland cement. The remedy was of course to shut off the sea-water, which was always effectual, as he had proved; and, fortunately, there was now no difference of opinion amongst the many chemists, both English and foreign, who had examined the question as to the cause of an occurrence like that referred to, nor amongst

[1] Minutes of Proceedings Inst. C.E., vol. lxxxvii. pp. 65 *et seq.*

[2] *Ibid.* vol. cvii. pp. 31 *et seq.*

engineers who had had to deal with the matter, as to the proper remedy. Mr. Hayter.

Two questions naturally arose. The first was, why were not the foundations of the Belfast Graving-Dock carried down to the clay, instead of being laid in the fine sand charged with water? for good clay was to be found at a depth of only 3 to 4 feet from the bottom of the dock. The answer to this seemed to be that the borings made at the outset did not reveal the existence of clay. They were to a great extent made in sand charged with water; and when borings were made in sand, silt, or like material holding water, the material ran down the bore-hole and mixed with that brought up, rendering it difficult to say what kind of strata had been penetrated. The explanation did not appear to be altogether satisfactory, but there was no doubt that borings in such strata were as a rule unreliable. The other question was, why were not the walls backed with clay—of which there was plenty to be had? or why were they not "rendered" at the back with asphalt or Portland cement? The apparent reason was that it was not then generally known that porous Portland cement concrete would, under the conditions prevalent at the Alexandra Graving-Dock, be injuriously affected by salt water.

Three measures were suggested to restore the graving-dock. The first—of a tentative kind—was to take out the cracks which had occurred and to fill them with Portland cement grout; to remove all the damaged material and to replace it by strong concrete. This was recommended to be tried first, because it was the least costly proceeding, and because the salt water of the adjoining tidal River Lagan permeated the sand backing and, being charged with silt, would perhaps have deposited some of it in the sand, rendering it more or less water-tight, so that the dock chamber might possibly be kept dry by the pumps. It was well known that both in this country and abroad many graving-docks had to be kept clear of water leaking into them by pumping it out, to enable them to be conveniently used. A second remedy which might have to be resorted to, would be to drive a row of sheet-piles across the entrance passage, so as to prevent the water from getting underneath the sill and chamber of the dock and disturbing the underlying sand. If those remedies were not effectual, the only alternative (the third remedy considered) would be to dig a trench down to the clay, whenever there were indications that deterioration of the concrete was in process, and fill the trench with puddled clay carried up well above high-water mark. That would entirely shut off the

Mr. Hayter. salt water from such parts of the dock and would certainly be effectual. Of course the remedies would be costly and would involve the expenditure of, it might be, between £2,000 and, say, £15,000. The dock was a large one, and, eliminating certain items given by Mr. Kelly and not necessarily belonging to it, the cost seemed to have been between £130,000 and £135,000; so that, if the cost of repairs was included, it would not after all be an expensive dock, considering its size. An item, however, which would have to be added, was the capitalized cost of pumping, if it should have to be resorted to in order to keep the dock-chamber dry.

The Hon. R. C. Parsons. The Hon. R. C. Parsons mentioned a point with reference to the endurance of the Halifax Graving-Dock. A year had passed since the Paper was written. The secretary of the Dock Company, who was prevented by illness from being present, had written the following letter:—"I may say that the dock in all its departments works well, and in point of its endurance nothing is left to be desired. It has had the test of a very severe winter, and has sustained no damage beyond the scaling of a small portion of the surface. The cost of maintenance is absolutely nil." He had omitted to mention that the cement used in the concrete was English and was supplied by the West Kent Cement Company.

Mr. Thorowgood. Mr. F. N. Thorowgood wished to ask a question with regard to the cofferdam of the Halifax dock. It was made by tipping clay on to the surface of the rock and driving piles into it. He would be glad to have some notion of the amount of clay, the width of the bank, how long the clay was deposited before the piles were driven into it, and whether there was any leakage between the bottom of the clay and the rock. Mr. Pickwell, in the Paper on the Newport Graving-Dock, had stated that the materials of the concrete were mixed dry in the following proportions: 7½ measures of broken slag, 2½ of sand, and 1 of cement, each of 3 cubic-feet, and those became 22 cubic-feet of concrete, showing a shrinkage of one-third. Mr. Thorowgood had found at the Madras Harbour Works that the shrinkage was very nearly the same. The proportions used were 10·28 cubic-feet of stone, 4·16 cubic-feet of sand, and 1·66 cubic-feet of cement, making 16·10 cubic feet altogether: 42 of those charges went to make a block of 18 cubic-yards. The total amount of dry material was 776 feet, but mixed as concrete it became 464 cubic-feet. Mr. Pickwell had mentioned that the concrete weighed 175 lbs. per cubic foot, which was 12·8 feet to a ton. That seemed very heavy,

especially as in another part of the Paper the Author had described the broken slag as measuring 26 feet to a ton. The weight of ordinary concrete was 139 lbs. to 142 lbs. per cubic-foot. On the River Tyne they used blocks of copper- and puddler's slag, which he believed averaged 13 to 14 feet to a ton; so that Mr. Pickwell's concrete of 12 or 12·8 cubic-feet to a ton appeared to be uncommon. Mr. Thorowgood.

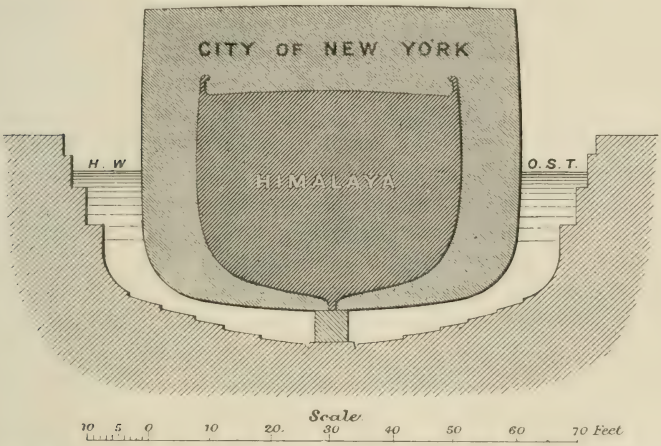
Mr. W. R. Galbraith was surprised to find that the latest efforts in Belfast had only produced a rather small dock. The Alexandra dock was only about 50 feet wide on the floor, and on the blocks at high-water only 92 feet. He thought that Belfast had not looked far enough ahead as regards the size of the steamers to be built. His firm was about to construct a large graving-dock at Southampton for the South Western Company and it had been his duty to consider the question of the steamers of the future. He had made inquiries of various parties, amongst others of Messrs. Thompson of Glasgow, as to their idea of the requirements of graving-docks to take the largest steamers that might be expected to be built in the next, say, thirty years. Their view was that steamers 800 feet long and 80 feet beam should be provided for. Certainly a steamer of anything like that capacity would not get into the Alexandra dock. One feature of the dock was its division into three parts, 300 feet, 200 feet, and 300 feet. There were many steamers over 500 feet in length, for which the divisions would be of little use. If a vessel occupied the inner portion of the dock for 2 or 3 months, it would be impossible to get one of the large ocean steamers in. The "City of Paris" and the "City of New York" were 565 feet long; he did not know the length of the "Majestic" and the steamers of the White Star Line, but supposed it approached those figures; the new Cunard steamer was 625 feet long by 65 feet beam. The Alexandra dock, therefore, was small, not only as regarded steamers of the future, but for those already built. With regard to the failure of the concrete, the magnesia theory in his opinion hardly accounted for it. How was it that the concrete failed only here and there, and not generally in the innumerable sea-walls and concrete structures exposed to the action of the sea? He knew docks where the sea had access to both sides of concrete walls, where there had been no failure at all, and sea-water was commonly used in mixing the concrete. He might mention that some time ago his firm built some large viaducts in Devonshire, and used concrete blocks for turning the arches. They were made, but did not set, and, on investigation, it was found that the sand had been Mr. Galbraith.

Mr. Galbraith. obtained from one of the mines, and had been charged with mundic which destroyed the cement. He questioned whether those partial failures did not arise from the use of inferior cement. The dimensions of the proposed graving-dock at Southampton were not settled, but it was intended to be about 700 feet long on the floor. The width of the dock on the floor would be 87 feet 6 inches, and at the coping level 112 feet 6 inches, which would certainly take the largest vessel that might be expected to be built for many years to come; and by lengthening at one end, for which provision was made, there would be room for vessels even of the size contemplated by Messrs. Thompson. It was a pity it was not ascertained that there was boulder clay within 3 feet of the floor of the Belfast dock, and that the foundations were not carried down to it. Borings could not always be depended upon. He had seen borings indicating greensand, where he was certain that the formation was sandy clay. It was impossible to rely upon borings unless they were freed from water.

Mr. Giles. Mr. A. GILES, Vice-President, said that the Papers which had been read upon the construction of graving-docks contained many matters of great interest. He would first deal with the question of cost. He was sorry that there was no account of the cost of the first dock under review. An estimate of £135,000 was given for a dock smaller than the one executed, and he could not conceive that the larger dock, with all its accessories, was executed for that amount. Putting the Halifax Graving-Dock at a cost which might probably be called £150,000, the Biloela Dock at £260,000, the Belfast Dock at £107,000, and the Newport Dock at £25,000, the figures worked out thus:—the Halifax Dock cost fully £2 per yard of cubical capacity, the Biloela Dock £3 10*s*., the Belfast Dock £1 13*s*., and the Newport Dock £1 3*s*. As graving-docks, by themselves, were not generally good commercial speculations, it behoved designers and constructors of such works to exercise the strictest economy in their execution. He could not help feeling that of the 4 docks described, that at Newport was by far the cheapest and most efficient for the money expended upon it. He had experience of a dock which he constructed 40 years ago, and, to show that Southampton in those days was not behind the age, he had placed a section of it on the wall, with the crack ship of that day, the "Himalaya," in it, *Fig. 1.* In the sections it might be seen how closely the shape of the dock followed the shape of the "Himalaya." The section of the "City of Paris"—a vessel of something like 9,000 tons—on the same diagram, showed that the sections of ships of the present

day had been entirely altered, and that a different section of dock was required. If it had not been that the blocks were exceptionally raised above the floor of the dock, the "City of Paris" could not have been docked; and so it was with all modern ships. Their belly, as it might be termed, for a considerable length amidships, was nothing more than a square box, and the speed was given to the ships by the aid of a fine bow and stern. In old times it was thought necessary to make a dock which would stand the upward pressure when the ship was removed, and considerable expense was incurred for the purpose of making a very strong invert to resist the pressure, which amounted in leaky ground to something like 1,500 lbs. per square foot. Mr. Barry, in con- Mr. Giles.

Fig. 1.



SECTION OF DRY DOCK AT SOUTHAMPTON, BUILT IN 1853, WITH THE "HIMALAYA," OF 1853, AND THE "CITY OF NEW YORK," OF 1890.

structing the Barry docks, had initiated the idea that it was more economical to pump out the water which leaked into a graving-dock than to make an invert of the great width necessary to accommodate modern ships. Looking at the section of the Barry dock, the difficulty of making an invert strong enough to carry two ships abreast, if there had been any great leakage in the centre, would be apparent. The bottom of a dry dock was always more or less damp; and if there were no leakage in the docks it was sure to occur in the gates or caissons. Coming to the question of caissons *versus* gates, he had made some docks with gates and others with caissons. He preferred gates, but there were difficulties of situation in which

Mr. Giles. they could not always be adopted. For instance, if they were limited in length, a caisson could be worked in less length than a pair of gates. Speaking from his own experience with a pair of gates 80 feet wide, he had seen 3 vessels docked between daylight and dark. One vessel was taken in, repaired, and then taken out again; another vessel was taken in and repaired on the same blocks, and taken out again; and a third vessel was also treated in the same manner—all being done between daylight and darkness. He did not think that could be done in any other dry dock in the kingdom. The Author had stated that the Biloela dock had a caisson which cost £17,000. The Belfast dock had two caissons which cost £8,759, and the Newport dock had two pairs of gates costing £1,450. Mr. Giles had made a pair of 80-feet gates forty years ago which cost £5,000. He therefore maintained that, in respect of economical construction, gates were far superior to caissons—they were more handy to open and shut and much quicker in operation. At the same time, a caisson possessed advantages which could not be obtained with a gate; it would form a bridge for railway- or cart-traffic. He did not say it was impossible to get such a bridge with a pair of gates: it would be a little more difficult, but not quite so convenient. But, beyond that, he did not see any particular advantage possessed by caissons over gates if there were sufficient room in which to work the latter. In the Paper on the Newport dock, attention was specially drawn to the construction of the work, particularly as to building the side-walls in trenches. That was a method he had adopted many years ago, considering it cheaper than excavating the whole area of the dock with wide slopes. He quite agreed with the experience of one of the Authors, who had said that poling-boards were not altogether satisfactory in deep trenches. They were apt, in slippery ground, to allow the stuff to run under and give trouble. No doubt many engineers had had similar experience and had found that for deep trenches in soft ground, sheet-piles were superior to poling-boards. With regard to concrete, it varied, according to the Papers, from 6, 7, and 8 to 1; and he had heard 10 to 1 mentioned. He had never adopted concrete so poor as 10 to 1 except for very common purposes. Generally speaking, 7 or 8 to 1 would make a strong and water-tight concrete. Concrete when built in mass, as he had generally used it, should be well trodden in and rammed. It would then be quite water-tight. In addition to that, he considered it desirable, in building huge masses of concrete, to grout the top of each course before putting in a

new one. With regard to the Belfast dock, it was stated that the sills were level with the floor; and that there were two intermediate sills dividing the dock into 3 portions, two of 300 feet and one of 200 feet. He thought that was a mistake and that it would have been far better to divide the dock into two parts. The Paper did not say whether the outer caisson-sill was level with the blocks or not, but the inner caisson-sill must be level with the floor. It was always desirable that the blocks should be about level with the sill, therefore, the sill should be 2 or 3 feet higher than the floors. It was impossible to dock a ship of such a section as that of the "City of Paris" on the floor of the dock; there must be 2 or 3 feet under her, and, in fact, there ought to be 5 feet. If any repairs were wanted to the bottom of the ship, he would ask how they could be effected if she were sitting on the bottom, or only 2 or 3 feet from the bottom? If the "Howe" got into the dock, how would the ship-builders be able to repair her, with only 3 feet between her bottom and the floor of the dock? Another question was as to the leakage through the concrete in the Belfast dock, which he had seen. His son, who was now engineer to that dock, was doing his best to stop the leakage, and so far had done it successfully by adopting the course the President had suggested—cutting out the bad parts of the concrete, and caulking. The caulking had proved effective, and the concrete which had been cut away was afterwards renewed. Something had been said with regard to the weight of concrete. He confessed that 175 lbs. per cubic-foot was an excessive weight. Granite weighed only 166 lbs. per cubic-foot, and he did not think that concrete could be heavier than granite. He repeated that the wide difference in the cost and capacity of the docks under review should point to the conclusion that graving-docks, not generally remunerative *per se*, being only necessary adjuncts to harbours or other docks, should be carried out with the greatest possible economy. Mr. Giles.

Sir Benjamin Baker, K.C.M.G., Vice-President, was aware that it had often been remarked that Papers on construction, such as those just read, were apt to give rise to little debate and might therefore be relegated to the "selected" group without discussion; but he thought there was a difference, and that Papers which had passed the criticism of a meeting of the Institution had more value than others, because he was afraid that the members did not read the whole of the four annual volumes of Minutes of Proceedings; and, even if they did, there was no possibility of correcting errors except in a discussed Paper. As an instance in Sir Benjamin Baker.

Sir Benjamin Baker.

point, when he had taken up the Papers under consideration and like most critics had begun at the end, he had been struck with the point that Mr. Giles had just mentioned, about the weight of concrete in the Newport dock. He noticed also that the Author had investigated the strength of the concrete invert as a beam. That had attracted his attention, because he knew at a glance, from experiments of his own, made with concrete beams, that the stability of the inverts must depend upon causes other than transverse strength, but exaggerated ideas were not uncommon as regards the span over which a concrete or masonry beam would carry its own weight; and, as flat inverts were frequently used, the subject was worth consideration. Of course, carrying its own weight implied research as to the weight of the concrete, and at the end of the Paper the weight was given as 175 lbs. per cubic-foot. He had never made concrete heavier than 151 lbs., and in that case it was not dry but had been well soaked in water: 175 lbs. seemed heavy, but he observed that it was made of steel slag, and that might account for it. But, on looking back to an early part of the Paper, he observed that the steel slag only weighed 26 cubic-feet to the ton. That was not heavier than broken stone. 175 lbs. per cubic-foot was about 13 feet to the ton, and how the 26 had become converted into 13 by the addition of the cement and sand specified, he could not quite see. Taking the weight of the concrete at about 18 feet to the ton, which was a very usual weight, and being lighter than the 175 lbs. concrete given in the Paper, would be in favour of the floor carrying itself as a beam; and, taking the constant which the Author had derived from Mr. Colson's experiment, the 4 tons would be the breaking load of a beam 1 foot square and 1 foot long, and 4 tons in the centre would be equivalent to 8 tons distributed. In deriving the constant, the weight of the beam should of course have been included; but 8 tons would be higher than the average, and might be accepted as including the weight of the beam. Multiplying that 8 tons constant by the number of cubic-feet per ton, 18, the result would be 144. The square root of the product of the constant and the number of cubic-feet per ton of any kind of concrete would give the span of a beam 1 foot square of that concrete which would carry itself. The square root of 144 was 12, and that was the span which a beam a foot square of such concrete would carry itself just on the point of breaking. The case they were considering was 48 feet span, which was four times 12 feet, and the thickness, in order to carry itself, must go up as the square of the span; therefore the thickness required for that invert to carry its own

weight would not be 7 feet, as constructed, but 16 feet, and the invert could not possibly carry its own weight or stand the hydrostatic pressure as a beam. But it was stable, and the reason was that it was not a beam. The upward pressure of the water on the under side of the invert would be accompanied by a lateral water pressure at the back of the walls which would put a compressive stress along the whole of the invert, partially or wholly reversing the tension on the concrete. Applying those principles, and including the pressure of the earth as well as the pressure of the water, it would be found that they really got not a beam of concrete with tensile stresses, but what might be called a concealed arch in the thickness of the concrete invert, and that there was ample strength for the necessary stability, the whole of it being practically in compression, of course varying in intensity. With regard to concrete beams, the constant taken by the Author was 4 tons at the centre of a beam 1 foot long and 1 foot square for concrete 9 to 1 a month old. In his own experiments, and including the weight of the beams experimented with, he (Sir B. Baker) got 4·85 tons for 8 to 1 concrete six months old, 9 tons for 6 to 1 concrete (showing the great difference of strength between the usual proportion of 6 to 1 which their predecessors had generally adopted, and the 8 to 1 of modern times), 13 tons for 4 to 1 concrete, and 18 tons for pure cement; and the length of the beam which would carry itself would be simply the square root of twice the constant into the number of cubic-feet to the ton. As all those mixtures were about the same weight, 18 cubic-feet to the ton, practically his 8 to 1 concrete would carry itself as a beam 1 foot square, 13 feet 3 span; 6 to 1, 18 feet span; 4 to 1, 22 feet span; and a beam of neat cement, 26 feet span. He did not reflect in any way upon the actual strength of the dock invert; he merely pointed out to young engineers that although a flat invert looked like a beam, altogether wrong proportions would be arrived at if it were calculated as such; and further, that being really an arch in principle, regard should be had to this fact in putting in the concrete, so that any vertical joints should radiate as if the invert were curved. Another point to which attention might be directed, was that a constant derived from an experiment with a small beam, or anything of that kind, would necessarily apply to a large beam or mass of material. Such a proceeding was certainly not correct with regard to concrete, which was peculiarly liable to variations in quality. They might get a small beam made very uniform in quality, but that was a very different thing from getting an invert of large area and thickness of the same uniform

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quality; therefore it was necessary to apply a lower constant in the latter case. There was a good deal of confusion in early days from doing the same thing with specimens of wood. Tredgold, Barlow, and others took very straight pieces of pine, and derived constants which, when applied to large baulks of timber, gave a strength two or three times as great as the baulk of timber was found to be. Another point was that if tensile stresses were unavoidable a large factor of safety would be necessary in the case of masonry or concrete. Bearing upon the general question of the value of theoretical investigations of strength, in cases such as a flat concrete invert, as compared with direct practical experience, he might say that several cases recently had made him a little nervous as to whether the results of the high technical training of the present day with many young engineers did not lead to a dangerous confidence in theoretical deductions and the use of formulas. No one could charge him with contempt of theory; but cases had been brought under his notice rather frequently of late showing too great confidence on the part of young engineers in theoretical deductions; in preference to going to the same extent as their predecessors had been in the habit of doing to previous examples, in order to see what was the right proportion to adopt in a particular work. Only a few days ago a young engineer at a judicial inquiry attacked the stability of a work, not because it had shown any sign of failure or weakness, but simply because the theory from which he calculated its strength led him to think that the work should have failed. He did not seem to see that if his theory was at variance with practical observation, he ought to revise his theory and make it fit in with the facts. On the theory advanced, the work must have failed unless the tensile strength of green brickwork in mortar was such that a rope could be constructed of that material which would carry its own weight hanging vertically for a height of 220 feet. That consequence did not strike the young theoretician as at all absurd. Another case was from the Antipodes, and that was really so good that he would like to read out of a Blue Book, containing a report of the proceedings of a Royal Commission, one or two questions and answers in illustration of the point he was referring to. "Q. How long have you been an Associate Member of The Institution of Civil Engineers? A. About two years. Would you like to know why it is such a short time? Q. I did not ask you. A. Well, I would like to qualify the answer. The reason I did not become an Associate Member before was that when I contemplated coming to Australia, I was

certainly not aware that they thought so much of the fact that a man was a member of the Institution; but when I arrived here, I found, to my surprise, that they thought more of that Institution, in which the greatest number of duffers that I know in the profession are congregated, than of the University degree of Master of Engineering, which I hold, one of the highest in the United Kingdom. Learning that such was the case I became a member, as I say, two years ago. As a matter of fact, I could have been a member at least ten years previously. Q. But you are not a member now? A. I am a corporate member now." That gentleman was labouring under the delusion that the degree of "Master of Engineering" in some strange way constituted a man an engineer. He proceeded in his evidence to talk about the admissible weight on the driving-wheels of locomotives for given weights of rails, and adduced calculations that were pitiful to contemplate. Sir Benjamin Baker never read anything more ridiculous in its way in his life. This "Master of Engineering" found no difficulty in calculating the stress per square-inch upon a rail under traffic to the hundredth of a ton and in condemning a certain rail as too light. He had not enough practical knowledge, however, to see that the critical time in the life of a rail was not when it was new, but when it had lost perhaps 20 per cent. of its weight by wear and rust, and he had only to apply his theory to a worn rail on the London and North Western Railway, or any other important line in the world, to find that the stresses which he considered should not be exceeded were universally exceeded as a matter of daily practice with perfect safety; and so his theoretical criticism went for nought. A case like this should serve as a warning to students against imagining that if they had taken a degree in engineering, or had left a University with the highest credentials, they were therefore necessarily engineers. No doubt they had been supplied with an invaluable box of tools, but if those tools were not properly used, they might cut their own fingers very badly and also injure their employers. Theoretical knowledge was no substitute for the practical experience upon which their predecessors in this Institution had chiefly relied. This was not only necessary in works of the kind they were discussing, which really were very complicated as dealing with concrete and masonry, but also when apparently simple problems concerned with iron or steel were under consideration. For example, to take a very simple case, who was there among their students who would not be perfectly prepared to tell them what was the maximum stress per square-inch on a tube of given

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diameter and thickness subjected to internal pressure of a certain amount within the elastic limit? They would work out the answer to any number of places of decimals. Say that it was 7·55 tons per square-inch. If the question was put to all the senior wranglers in the kingdom, they also would say unanimously 7·55 tons; but if put to three poor mechanics, like the Director-General of Ordnance Factories (Dr. William Anderson), Sir Frederick Bramwell, and himself, they would say, "We do not know." It might be 7·55 tons, it might be 12·55 tons; they could not tell nor even approximate to it unless they knew certain facts about the treatment of the steel which only practical men would consider of importance. That was a simple instance of the absolute necessity in practice of viewing with great suspicion theoretical deductions, which, from the great trouble involved in performing the calculations, often led one to attach too great value to the results.

Mr. Hawkshaw.

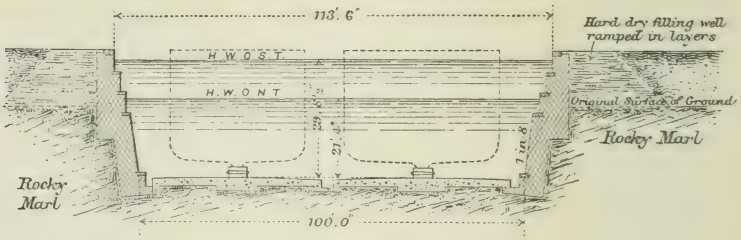
Mr. J. C. HAWKSHAW said he had some knowledge of the details of the Belfast dock, having been associated with the President in reporting upon it. There could be no question that the deterioration of the concrete arose from the action of the salts in the sea-water on the lime in a porous concrete. The process by which such deterioration was brought about had been fully explained at former meetings of the Institution and it was not necessary to discuss it further. Probably if the walls had been backed up by some impervious material or puddle and the foundations had been carried through the sand to the clay below, the deterioration would have been in a large measure prevented. He thought that in the present case the foundations ought to have been taken through the sand to the clay. But engineers had no more difficult question to settle than how to deal with running sand in a foundation—what depth to go into it. In the first dock-foundations he had charge of, there was a thick bed of running sand, and the foundations of the wall were carried down through it to a good boulder-clay below. This process led to endless difficulties, and at last, through pumping quantities of sand from under the river-bank, the bank gave way and the works were flooded. After that no further attempt was made to excavate the sand and the walls were built on 3 or 4 feet of concrete placed on it. The walls on the clay and on the sand had stood side by side for nearly 30 years, and for all practical purposes one foundation was as good as another. He had mentioned this because, although in the case of the Belfast graving-dock he thought the foundations should have been taken through the sand to the clay, he should not as a rule recommend such a course for a

dock-wall. Judging from his experience, if running sand were met with, it should be disturbed as little as possible, and the foundations should be placed as high as was consistent with safety. Mr. Giles had already alluded to the fact of the sill being at the same level as the floor of the Alexandra dock. It seemed a waste to put a sill down 2 feet lower than it need be. He did not know whether in the present case there was any special reason for so doing. If the Authors could give any account of their experience with different forms of keel-blocks, and state whether those of cast-iron or of timber were better, such information would be useful. Mr. Hawk-shaw.

Mr. J. Wolfe Barry was not aware that Mr. Giles would allude to the dry dock constructed at the Barry docks, but he thought it might be interesting to the Institution to hear some further particulars relating to it, as it possessed some novel features which were of importance when the question of the cost of such structures was considered. He fully agreed with Mr. Giles that the first cost of graving-docks was a most important matter, because it was difficult to make them pay under any circumstances. At the Barry graving-dock, they adopted what he believed was a new form (*Figs. 2* and *3*). The total length was 740 feet, it was 100 feet wide at the level of the floor and 113 feet 8 inches at the coping-level, with a width of entrance of 60 feet. The depth was 26 feet 8 inches at high-water of ordinary spring-tides. The sill was approximately level with the top of the blocks, which, he thought, ought always to be the case, as there was no object in incurring the cost of making the sills deeper than the tops of the blocks. The dock could accommodate 4 large ships at one time, viz., 2 ships 320 feet long, and 2 ships 340 and 355 feet long respectively. It could accommodate, by leaving out the central caisson, a ship of very large dimensions, viz., of any length up to 740 feet and of any beam up to 60 feet, which was the width of the passage between the inner and outer docks; but, usually 380 feet was as much as was required. He wished also to point out that the use of dry docks was now very different from what it was in the days of wooden ships. The iron ships of the present time were constantly coming into dry docks to be painted and for small repairs; and it was all-important to be able to accommodate them with dispatch. The case was very different from that of extensive repairs to wooden vessels, which involved much more time. That consideration ought to be borne in mind in designing the shape of a dock. In the Barry graving-dock, the inner dock could be used Mr. Barry.

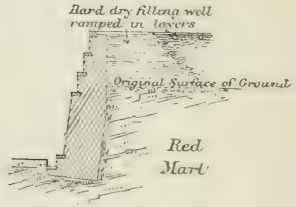
Mr. Barry. for repairs involving much time and the outer dock could in the meantime be used for more expeditious work. The shape of the modern graving-dock, especially of the altars, and the shape of the sides generally, were entirely different from the old form—a fact which should be recognized. The old form required much more shelving sides to accommodate the timber slides, in which the large and heavy beams required in the dock were manipulated, all of which was now done by steam-cranes travelling on the edge of the coping, swinging over the dock, and lifting in and

Fig. 2.



GENERAL SECTION
(WITH SIDE WALLS IN ROCKY MARL)

Fig. 3.



SECTION OF SIDE WALLS
(IN RED MARL)

BARRY GRAVING-DOCK.

out vertically. They also now shored ships on one side only of the vessel, to which a slight list towards one side of the dock was given by purchases on the masts. As the water receded short shores were put in between that side of the vessel and the dock and no other strutting was required. That enabled them to accommodate with ease four vessels in a dock of the shape indicated. With respect to the invert and walls, any attempt to make such a dock water-tight, as would have been necessary if the old form of dock had been adopted, would have entailed prohibitive cost. An invert 100-feet wide would have cost a very

large sum of money if it had had to be made strong enough to resist water-pressure, and he therefore came to the conclusion that it was far better to let the water come through the walls and also through the floor, and to put up an auxiliary engine in the main pumping-engine house, which kept the dock dry without using the main engine. The plan had proved an entire success. They not only inserted drain-pipes with self-acting valves in the walls, but all the concrete floor was laid with agricultural drain-pipes imbedded in it, so that any water rising through the floor was at once conveyed to either the central or side channels and so to the auxiliary pump. A little mistake had been made by Mr. Giles in thinking that the dock was wet; it was not so: all the water was concentrated in the three longitudinal drainage channels and flowed quickly to the pumps, and the floor was dry, wholesome and convenient. The cost of pumping the drainage-water was almost insignificant; certainly not of the least practical importance. The power of the auxiliary pumping-engine was about 20 HP. The cost of the dock itself was £61,500; the two caissons cost £7,600; the pumping machinery, £6,200; the sluice machines, £1,000, making a total of £76,300, or about £19,000 per ship. The site was favourable as to the foundation, and did not involve expensive walls, if the question of water-pressure were eliminated, as the soil was mainly of hard marl. On the other hand, the excavation was costly, involving the use of explosives. He had not divided up the cubic capacity in the way Mr. Giles had done, except roughly, since the remarks had been made. He thought it would be found that the dock was very much cheaper even than that at Newport, if cubical capacity were taken into account. The caisson which was adopted in preference to gates, carried a locomotive-road. If they had employed gates they must have had a swing-bridge to carry locomotives as well, which would have added very considerably to the cost. The dry dock he had described was not yet ready for trade, but he thought the Institution would be glad to know that a similar dock, in the hands of a private company was paying well—the last dividend being between 10 and 11 per cent.; and the financial success of an undertaking was always a satisfaction to an engineer. He wished to corroborate the views expressed by Sir Benjamin Baker on the subject of practical Papers such as those under consideration. He could not help thinking that engineers of all ages, and particularly young engineers, learned a great deal from the exchange of experience which took place in the course of such discussions; and he always

Mr. Barry.

Mr. Barry. hailed with great satisfaction the appearance of any one who would tell them what he had done, what failures he had made and what successes he had achieved.

Mr. Moberly. Mr. C. H. Moberly observed that the expense of the Biloela caisson was largely increased by the employment of delta-metal for the rollers and keel-bars, which were subsequently found to be unnecessary because the caissons were generally guided fairly well without rubbing against the quoins. That added something like £1,500 to the cost. In other respects, he thought it was a very good caisson. The falling-deck was perfectly automatic and the time taken for hauling it in was only about 5 minutes. As the caisson was drawn into the chamber, the end of the deck came into contact with a massive casting and was thereby forced down. When the caisson had been drawn out and nearly across the entrance, the end of the deck came into contact with cast-iron guides on the opposite side of the entrance, which forced it up. When the caisson was right across the entrance, the ends of the deck were held in position between the castings on each side of the entrance, and the deck could not fall. The ends of the faces of the caisson were connected at the air-chamber, and several feet above it, by water-tight plating; but elsewhere by diagonal bracing, so as to allow the water to pass through freely. That arrangement admitted of the air-chamber being so proportioned that only part of the weight of the caisson was buoyed up, leaving as much weight to press on the rollers as was required to ensure steady and safe working; and there was neither iron- nor water-ballast. The caisson had to work within a range of 6 feet of tide, *i.e.*, from 4 feet to 10 feet below the coping-level. When the water was 4 feet below the coping level, the unbalanced pressure on the rollers was 37 tons, and when it was 10 feet below, the pressure was 47 tons. As the tide-level was high, the air-chamber was also high; and the centre of displacement was about 4 feet above the centre of gravity of the structure, ensuring great stability.

Sir George Elliot. Sir George Elliot, Bart., M.P., said he had come to listen rather than to speak, and had been well repaid for his visit. He had been associated with Newport, especially with regard to docks, for 20 years, and was glad of the opportunity of learning what their neighbours had been doing at Barry.

Mr. Vernon-Harcourt. Mr. L. F. Vernon-Harcourt had taken an opportunity of seeing the Newport graving-dock on one or two occasions during its construction and had been struck by the very little room there was in which to build it, owing to the proximity of the Edith dock on one side and the road on the other. The place in which

it was built was one of those creeks known locally as Pills, where slips were of common occurrence. He understood therefore the difficulties which the Author must have experienced in putting in the piling and in reclaiming a portion of the Pill. In some cases in the River Usk, they had to go down 60 or 70 feet before getting to a proper foundation. It was therefore remarkable that the Author had been able to reclaim a portion of the foreshore and to construct the wharf in the way described. But it would be noticed that it was done by means of very long piles, and, if he remembered rightly, on one or two occasions the piling had come forward in the Pill, owing to the treacherous nature of the foreshore and to the pressure behind. With regard to the Belfast dock, the concrete seemed to have a small proportion of cement—1 to 8. Probably there was hardly sufficient small material in the concrete, because there were only 2 parts of sharp sand with 6 parts of coarse material; and it was, therefore, quite possible that the concrete was porous. If the sand was very sharp, it might not with the cement have entirely filled up the interstices between the stones. With regard to the failure of the concrete by the substitution of magnesia for lime in it, the danger was that the magnesia was readily hydrated by water and therefore increased in bulk. He would suggest that the water entered into combination with the magnesia, forming magnesian hydrate, and in that way increased the bulk of the material. He was glad to hear that the Belfast dock was being put in proper order, because it was very important to be able to use such a valuable and economical material as concrete for graving-docks, and as it had been used so successfully at Newport, there appeared to be no reason why it should not be used with equal success in other places. Mr. Vernon-Harcourt.

Mr. W. Stopford Smyth wished to offer a few remarks on what had been said as to the Newport graving-dock. He might mention that there were altogether 5 graving-docks at Newport. A question under the consideration of the Newport Alexandra Dock Company was whether extra accommodation to be provided for repairing vessels should be in the shape of a floating-dock or a graving-dock. In the case of the proposed enlargement of the graving-basin at the Alexandra dock, the extra width would be obtained by building the new north wall in trenches and afterwards excavating between the new and old north walls. The foundations of the old north wall would support the second set of keel blocks, cranes being employed to lift or lower the materials required for repairs. A length would be added, admitting of gates placed at a convenient point, dividing the dock into two Mr. Smyth.

Mr. Smyth. portions. The inner length could be reserved for vessels requiring considerable repairs. The outer length, of double width, would be for vessels to be painted and wanting slight repairs only. When considering the relative commercial value of graving-docks and pontoon docks for repairing vessels, if a graving-dock were entered from a wet dock, the depth of sill of the graving-dock would be independent of the contingencies attached to an entrance from a tidal river, and might be limited to the light draught of the largest vessel frequenting the wet dock, as it was extremely rare for vessels in burthen to have to enter a graving-dock. Pontoon docks, he need not say, had immense advantages. They offered attractions to vessels going to port, because captains were conscious of the fact that they could place their vessels on a pontoon in a few hours and examine them without loss of tide, which was a great advantage. Entering a graving-dock might or might not be an expensive matter, but at all events, it took time; whilst with the assistance of a pontoon or floating dock a vessel could be examined in a few hours. With regard to the construction of docks, he believed that if engineers of the old school had their choice, they would rather, as a rule, adopt masonry; but he thought that in many respects the iron dock was superior to masonry. He would ask members of the Institution who had experience in the matter to consider whether graving-docks were not as a rule made too deep already. A floating-dock could be made to carry, say, an ordinary vessel, 350 feet in length, for a comparatively small sum, but to make a dry-dock of the depth generally employed was a much more expensive affair. It had been suggested that graving-docks should not be made so deep as formerly, and that if they were built of reasonable depth and of light draught, they could be constructed more cheaply, put up more rapidly, would offer more effective service, and pay better—which was an important point—than deep docks. The advantage of having shallow docks was that ordinary vessels with light draught could get in, and the amount of water to be pumped out was not a great matter. With regard to accommodation, if shallow graving-docks were adopted, they might have accommodation for three vessels at the cost of the iron dock for one vessel. If the admissibility of the shallow dock were allowed, it was an argument for placing in the neighbourhood of large docks many more graving-basins than at present formed the equipment of a large dock. Perhaps at some future time an opportunity might occur for bringing before the Institution a

comparison of the utility and commercial value of a floating dock as against a dry-dock, a discussion upon which would be of considerable value. Mr. Smyth.

Sir Frederick Bramwell, Bart., Past-President, said he did not know that the question of floating docks would have been entertained. As, however, it had been brought forward, he might remark that he had had some experience with regard to floating docks and that there were many things to be said in their favour. In that kind of dock, when properly constructed, the amount of water to be pumped out in docking any particular vessel was extremely small, as was evidenced by the fact that, instead of the large pumping-engines needed for the other kind of dock, a pair of 12-inch cylinders on each side of the dock would do all that was wanted, and in that way they could readily dock a vessel of 2,000 or 3,000 tons in three hours. If the sides of the docks were made, as he preferred, with an open framework, with suitable floats in the framework to preserve the equilibrium of the dock, such docks were very useful indeed in tropical climates, because they were floating on the surface of the water; there was a free draught of air right through them, and, as a mere matter of comfort to the men at work and of rapidity of drying the paint put upon the ship's bottom, their use was superior to that of docks with closed sides. Moreover, if they wanted to take in a ship of shallow draught, they only had to lower the dock to the exact point required and raise it again. The water to be pumped was very much in proportion to the amount of work to be done; whereas, in the case of a deep dock taking in a shallow ship, it was necessary to pump the dock out to the bottom. He thought there were many instances in which a floating dock was preferable to a graving-dock. On the other hand, where there was a very large trade and where there was a good foundation to begin with, it might be that the solid dock was better. He was sure, however, that the floating dock was well worthy of the attention of any engineer who had before him the problem—"of what nature shall I make the graving-docks I have to provide for the port about which I am advising?" With regard to the relative cost, with the present price of steel, he might say that, as a rule, certainly where the foundations were bad, a floating dock would compare favourably with the other, but where the foundations were good he imagined that the solid dock would probably be the cheaper of the two. But he thought that the balance would very much depend upon the particular circumstances of each case. At all events he could say from personal Sir Frederick Bramwell.

Sir Frederick Bramwell.

knowledge of the dock which he designed in 1867 and which had been working for the last 20 years, that such docks worked without the slightest difficulty and answered very thoroughly the purposes for which they were intended.

The Hon. R. C. Parsons.

The Hon. R. C. Parsons, in reply, said that Mr. Thorowgood had asked some questions about the cofferdam made at the mouth of the Halifax dock previous to the excavation being undertaken. It was a rather peculiar case; but he did not fancy that it was unique in the history of dock-construction. The bottom of the entrance was levelled as nearly as might be; but it was carefully cleaned and, as far as possible, freed from all debris. As soon as that was done, a wide bank of stiff puddled clay was tipped in for a depth of some 10 feet and piles were driven down to the surface of the rock, into which the points penetrated 8 or 10 inches. The cofferdam was then completed in the ordinary way, and scarcely any leakage took place between the puddled clay and the rock. Any leakage which occurred did not increase during construction. Mr. Giles had drawn a comparison between the cost of the several docks described; but he had not taken into consideration that the Halifax graving-dock was the only one described which had been excavated in solid rock of a hard description. It was impossible to arrive at the cost of that dock for the following reason. The project was made some years before its construction, and the finances were of a very unsatisfactory nature; so much so, that the dock was practically constructed by paper, and the amount of cash paid was small. He was under the impression that the cash expended did not exceed £135,000. With reference to the manner of closing the dock, the question as to whether gates or caissons should be employed for the purpose was carefully discussed. One of the principal reasons for the adoption of a caisson was the severe weather which occasionally occurred at Halifax and the amount of floating ice which came down the river. It was thought that a caisson would be much safer than gates in view of ice accumulating inside the dock and round the backs of the gates, if they had been adopted. In addition to that, the dock company possessed a slip, and it was arranged that the caisson should be hauled up in case of repairs or painting being required; whilst in the case of gates, the outer side could never be reached for repairs, which was a very important matter. Further, as Mr. Barry had mentioned, a caisson was convenient for passage across the front of the dock, which was important in this case owing to the local circumstances. From various precedents he had found that the cost of an ordinary

caisson compared favourably, as a rule, with that of dock-gates; and he believed that in the present instance the caisson was constructed for a sum less than would have been required for gates, if they had been adopted. It was stated in the Paper that there was but little leakage in the dock. When considering the question of the thickness of the floor, the point referred to by Sir Benjamin Baker appealed forcibly to him, viz., how little resistance the bottom of a dock was able to exert against water-pressure from without. The difference of specific gravity between concrete and water was little more than as 2 to 1, so that a slight pressure underneath the floor of a large dock would be sufficient to lift it. The dock in question was carefully drained beneath the concrete, and the drains remained open, the consequence being that if any pressure came under the floor, as Mr. Barry had explained, the water was taken into the well, and no pressure could possibly come on the floor of the dock. In that way a perfectly safe floor had been secured. Mr. Hawkshaw had asked a question about the keel-blocks. There were two sets; the ordinary blocks at the bottom, and also a set of bilge blocks supplied at the wish of the Admiralty. The bilge blocks, as soon as the vessel was in place, were drawn under her, and in that way she was shored up whilst the water in the dock was being pumped out. The Hon. R. C. Parsons.

Mr. E. W. Young, in reply, said that remarks had been made as to the cost of the Biloela dock. The explanation was the exceedingly high cost of labour in Australia, which might be taken on an average as double that in this country; so that dividing the cost by two would be a proper step in comparing it with docks built in the United Kingdom. Being a Government work, the question of its paying commercially was probably not much considered. A dock capable of taking a large man-of-war or other large steamers was wanted. The plan referred to by Mr. Giles and Mr. Barry for making docks with porous floors, allowing the water to pass through, was a novelty to him. He was no authority on the subject; but it struck him that a small amount of leakage would not obviate hydraulic pressure if any water had free access to the bottom of the dock. With reference to the timber-slides which it had been usual to provide in docks, he believed they were seldom used. The custom was a survival from the days of timber ships, when a great deal of timber had to be sent down. The shores used in supporting the ships were passed into the docks at high-water, floating on the surface; as the water was pumped out, they were used to shore up the ship, and when the water was re-admitted, the shores were floated up to the top of Mr. Young.

Mr. Young. the dock, and were pulled out on to the quay. The timber-slides were undoubtedly weak places in docks, and if they could be dispensed with it would be an advantage. Sir Frederick Bramwell had referred to the relative value of floating- and dry-docks. If there were a solid foundation, a dry-dock might be preferable; but in many cases, such as in the Biloela dock, the solid foundation involved the excavation of a large quantity of rock, which added greatly to the cost, being paid for at the rate of 8*s.* per cubic-yard. Not only was all that rock excavated, but there was a large cliff on the top of it, which was first cleared away to form a site for the dock, and added another item to its cost.

Mr. Kelly. Mr. W. Redfern Kelly, in reply, said there could be little doubt that the source to which the failure of the Alexandra graving-dock was primarily attributable, was the porous character of the concrete. Its permeability was such as to afford free passage to sea-water through it from the tide-way to the interior of the dock; and this water, which was charged with magnesia, being thus free to percolate through the concrete work, was constantly renewed and, with each renewal, the precipitation of magnesian hydrate continually proceeded, with destructive results to the concrete. Careful observation of the disintegrated materials, aided by chemical analyses, had been made under various conditions, and all confirmed the opinions expressed by Messrs. Hawkshaw and Hayter, whose first suggested remedy had been applied with satisfactory results. With regard to that question it was important to note, that it was only where the concrete walls were subjected to the unbalanced pressure of the tidal water that the destructive influences appeared to take effect. In other cases, where the sea-water did not fall below the low-water level of the wall, concrete, bearing the same relative proportions and being in all other respects precisely similar to that of the Alexandra graving-dock, had not been known to fail. In this connection, Mr. Galbraith had observed that "he knew docks where the sea had access to both sides of concrete walls, where there had been no failure at all." This appeared to be, generally speaking, the normal condition in such cases; the destructive action of magnesia was felt in those instances where the sea-water was forced through the concrete under pressure, as in graving-docks, or in entrance-locks, which on being pumped dry were subjected to the unbalanced pressure of the tidal water from without; for, in those cases, it was continuous percolation and renewal of the sea-water which unquestionably did the mischief. With regard to the remarks of Mr. L. F. Vernon-Harcourt as to the ratio of cement being small, Mr.

Kelly had seen some first-class concrete made on such a specification as that referred to. Contractors, however, were sometimes tempted, from motives of economy, to introduce gravel which was perhaps already surcharged with sand; and in such a case it would be obvious that to introduce the amount of sand specified by the engineer, in addition to that already contained in the gravel, would be to produce a weak and porous concrete. As to the filling up of the interstices between the stones with sand, so as to secure a perfectly impermeable concrete, the fulfilment of this condition would affect the economy sought by the adoption of concrete in place of solid rubble masonry, in a locality such as that of Belfast, where gravel was not to be found conveniently or in large quantities on the foreshores of the estuary, and where broken whinstone, or sea-washed gravel, could not be procured at a less cost than 4*s.* 6*d.* per ton. As to the question why the foundations of the dock were not carried down to the underlying boulder clay (which it had been assumed lay at about 2 or 3 feet below the bottom of the present dock), it could only be said that the borings made for the Alexandra graving-dock works, gave indications of a stratification widely different from what was actually found to exist—a striking example of the unreliable character of borings made in water-bearing strata. Referring to the size of the Alexandra graving-dock, it should be borne in mind that this dock was not constructed solely for the accommodation of the ship-building industries of Belfast. It was intended to meet the requirements of such large vessels as would, during the next fifty years, be likely to make Belfast their port of call, and at the same time to accommodate the largest class of vessels yet built at that port, or which might be built there for very many years to come, excepting, of course, the ideal leviathans to which reference had been made. As to the question of the non-utility of the system of compartments, adopted in the case of the Alexandra dock, any vessel up to 500 feet in length could be docked in one of the doubled compartments; and cases where vessels of such a length required the use of the dock were certainly not rare. Again, instances were not uncommon of already tolerably long vessels requiring to be docked, for the purpose of being still further lengthened by inserting a new section nearly amidships; and in such cases the two inner compartments of the dock had invariably been locked up as one, sometimes for a considerable period; the outer section was, however, still available for the reception of vessels up to about 300 feet in length. The practical utility of the existing arrangement had been amply

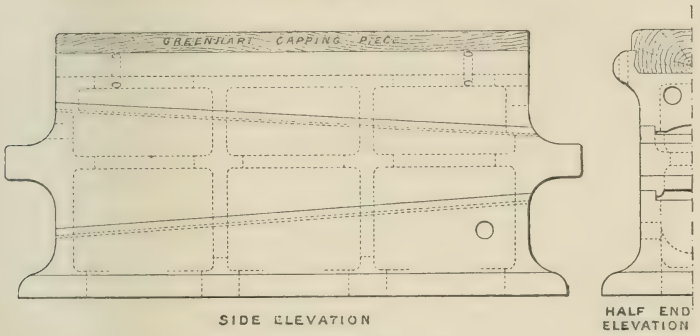
Mr. Kelly.

Mr. Kelly. confirmed by the experience of the past few years in the working of the dock. It had been suggested by Mr. Giles that the entrance sill of the dock should be placed higher by 2 or 3 feet than the dock floor. In the Belfast dock all the sills were level with the floor of the dock; by which means the keel-blocks could be laid upon the floors, and the working-space underneath a vessel would be the same throughout the entire length of the dock. As to the outer sill, it would be seen by referring to Fig. 1, Plate 4, that, by placing the caisson-gate in the outer groove, an additional length of 14 feet could be secured, and, in this case also, the sill-floor was prepared with sunk seats for the keel-blocks. Were the sill so constructed as to be level with the tops of the keel-blocks, it would be apparent that a portion of the floor which was now available would be rendered comparatively useless. Further, the raising of the sill-floor to the level of the keel-blocks would have the effect of reducing the present available width of the entrance at that particular part where ample width was most needed, that is to say, where the widest part of the bilges of many vessels would be most likely to strike the sides of the entrance in passing in or out. No saving of material would be effected by raising the sill, but, on the contrary, the cost would be increased, as the dock foundations would be carried down to the same level in either case; and, if the outer sill were raised to a higher level than that of the two inner sills, the two caissons would clearly not be, as they now were, interchangeable. As to the question of the adoption of caisson-gates instead of hinged leaf-gates, the former type of gate clearly possessed some advantages over the latter. Caissons could be made to suit several entrances in the same or neighbouring docks. Caisson-gates could be utilized as roadways, or railways, across dock-entrances, which might be in many cases a matter of considerable importance, especially under circumstances where a bridge would otherwise be a necessity. They required less space than did leaf-gates. They could with facility be docked, beached, hauled up on a slip, or laid upon a gridiron for examination, repair, or painting. Whilst gates, which were perhaps more liable to become deranged, could not be examined, repaired or painted, with anything like equal facility. And, from the fact that a pair of leaf-gates for an entrance of 80 feet in width had cost £5,000, whilst one of the caisson-gates for the Belfast dock, for an equal width of entrance, had cost £4,380, and one for the Barry docks had cost only £3,800, it would appear that the superior economy of the caisson-gate over the leaf-gate had been established. With regard to the question of

the relative cost of the graving-docks which had been described, it had been stated by Mr. Giles that, of the 4 docks, that at Newport was by far the cheapest and most efficient for the money expended upon it. It was not easy to discover upon what assumption this conclusion had been based. It seemed to him that the Newport and Belfast docks were scarcely comparable. For the former the figures £25,000 were taken, and for the latter the sum of £107,000 was assumed. The Newport dock was small compared with that at Belfast; the length of the former was only 350 feet, against 817 feet for the latter; the entrance was only 48 feet in width, against 80 feet in width; and its width at the coping-level was but 72 feet, against 92 feet. At Newport, neither engines, pumping-machinery, nor other contingent works, such as

Mr. Kelly.

Fig. 4.



Scale, $\frac{1}{20}$th.

CAST-IRON KEEL-BLOCK.

engine- and boiler-houses, pump-wells, culverts, &c., were required. With regard to the sectional shape of graving-docks, whilst there was much to commend a form with moderately shelving sides and regular altar-courses, there appeared to be little that could reasonably be urged against it. It was a matter of considerable consequence that as much light as possible should be admitted to a graving-dock; and since, as Mr. Barry had observed, "The iron ships of the present day were constantly coming into dry docks to be painted," it would be admitted that the freer the circulation of air around and under vessels thus docked for painting, the more rapid would be the drying process, and the earlier would the vessel be able to leave the dock. It had been stated by Mr. Young that the so-called timber-slides were not very much used. In the Alexandra graving-dock, where principally iron vessels were repaired or lengthened, those slides

Mr. Kelly. were very often used and were found to be of the greatest possible service—in fact they were indispensable. Large iron plates and bars, pieces of machinery, balks of timber, and other heavy materials, were constantly lowered or raised on these slides; and the silt deposited in the dock (sometimes in considerable quantity) during each admission of the tidal water, was, when collected in wagons, drawn up the slides to the surface. Under no circumstances was it permissible to lower or raise materials over or across the altar-courses. Again, the slides occupied but little space, being situated in every case beside a stair-way; and there did not appear to be the slightest reason why they should be allowed to be weak places in the dock. A question had been asked by Mr. J. C. Hawkshaw as to the relative value of iron and timber keel-blocks. Both cast-iron and timber keel-blocks had been in use at the port of Belfast for very many years, and the former kind certainly appeared to be preferable to the latter. *Fig. 4* illustrated the block referred to. The iron blocks were wedge-shaped, and thus were more easily and neatly adjusted than timber blocks. By removing the centre, or key-wedge, reversing the upper piece, and laying it upon the lower one, a difference in height amounting to 9 or 10 inches might be obtained. The tops of the blocks were capped with heavy pieces of greenheart. Iron keel-blocks were much more durable than timber, a fact which justified the increased first cost of the former. The pattern adopted for the Alexandra dock had been in use for more than 25 years in the Hamilton graving-dock at Belfast, and had found favour with ship-builders and others using the graving-docks during that period.

Mr. Pickwell. Mr. R. Pickwell, in reply, said that the limited space available led to the Newport dock being carried out by timbered trenches. With regard to the weight of the concrete, it had certainly astonished him to find that it weighed 175 lbs. per cubic-foot. He was glad that the question had been raised, because he had never come across concrete weighing so much. He had placed two samples of the concrete on the table, and would mention some figures extracted from his note-book as to the method employed to arrive at the weight. He took 7½ parts of broken steel slag, which weighed 19·35 lbs.; 2½ parts of sand, all lost in the interstices, 8·75 lbs.; 1 part of cement, 2·67 lbs. When that was mixed and measured in the dry state, it measured 33 cubic-feet, and when made into concrete, 22 cubic-feet. He assumed that ultimately the water evaporated from it. He had simply taken the dry weight, and that came out at 132 lbs. per cubic-foot. But the

slag was simply slag as it came in the trucks, not broken. Of course if the slag were broken, it would lie together and weigh considerably more. He had arrived at the weight by taking 3 or 4 truck-loads of slag as sent from the Panteg Steel Works. He had recently taken two samples out of the dock, one of skin-concrete and the other of mass-concrete. He had taken the water displacement of those two irregular pieces and then weighed them. The skin-concrete, 6 to 1, weighed 163½ lbs. per cubic-foot; and the 8 to 1 concrete weighed 134 lbs. per cubic-foot. He thought the explanation of the great weight of the concrete was that it was made from heavy steel slag. Reference had been made to some of the piles slipping forward in the Pill. There had been indications that the whole of it would have slipped forward if they had not taken time by the fore-lock. He might add that after the dock had been open for some months, the bottom had sustained a severe trial; the petroleum tank s.s. "Tankerville" was in dock for repairs, with all but one of her tanks filled with water and probably weighing 5,000 tons, when an explosion occurred, and the ship was blown up 18 inches off the blocks and fell again without apparently injuring the floor. Mr. Pickwell.

Correspondence.

Mr. Reid Bell presumed that in adopting a groove instead of a check for the caisson of the Halifax dock, regard was had to the provision for placing the caisson at the outer end of the fore-bay; but it seemed that sinking the caisson in this latter position would entail considerable risk. The object of the piers in the Biloela dock was presumably to allow short shores to be laid to the vessels' sides, and to give working room on the quay close to the vessel. It would be interesting to know how far the working of the dock proved their utility, as they must add to the cost of the walls. They would to some extent lessen the amount of water to be dealt with in filling and emptying the dock, and it was a difficult matter in arranging the cross-section of a dry dock to provide sufficient access for light and air round the ship, and at the same time to keep down the water capacity. In the Clyde Navigation Graving-Dock No. 1, the engineers, Messrs. Bell and Miller, cut off the walls round the body of the dock at 2 feet 6 inches above high-water, providing at that level a working-platform 30 feet wide round the dock, and the writer believed this plan was first adopted more than 30 years ago by the same engineers in the Meadowside Mr. Bell.

Mr. Bell. dock, built for Messrs. Tod and Macgregor. This allowed the sides to be somewhat steeper, and so reduced the quantity of water to be pumped and shortened the length of shores required. The form of the Biloela dock-head was well designed, as it gave the minimum water capacity, and the form of a vessel's fore-body exposed the skin well to the air without the necessity for great width at the coping-level. It would be interesting to have some additional particulars of the Stoney sluices here. Perhaps also the engineer would give his reasons for adopting the plunger-pumps, in place of the centrifugal pumps now so generally used. The use of crushed sandstone for sand at Biloela was noteworthy, and it afforded in many works a solution of the difficult question of providing good sand of uniform quality. With Portland cement, he thought that, provided the grains of sand were larger than the particles of cement, coarseness was not necessary, so long as it was clean and sharp.[1] He agreed with the practice of dispensing with punning in concrete work, having found the most satisfactory results from laying the concrete in 9-inch or 12-inch layers and simply working it with the edge of a shovel, sufficient water being used in mixing to allow the mortar to set well round the larger aggregate. In fact, the mortar in concrete should be quite as wet as that used for setting masonry. In the Belfast dock there was apparently no apron under the fore-bay, and without such an apron trenched into the solid it was difficult to see how a puddle-wall round the sides and head could isolate the dock, unless there were provision for carrying a puddle-dam right across the front of the dock. From the writer's experience of concrete walls under water-pressure, he was of opinion that no treatment of the face of a wall with cement or strong concrete would successfully staunch a leak once established. The strong concrete should be on the side of the wall against which the water-pressure acted. The 8 to 1 concrete (No. 2), of which the main body of the work was composed, would require at least one-third, and probably one-half as much again of sand and cement to fill the interstices of the aggregate, and the pockets left in the walls afforded direct entrance for the water to the body of the work. Regarding the Paper on the Newport dock, the writer could adduce experiments made by him at a concrete breakwater constructed at Emu Bay, Tasmania, some years ago. The stone for the concrete was a columnar basalt, weighing 183 to 184 lbs. per

[1] *Vide* "Results of tests made on Loch Katrine Waterworks Extension," Transactions Inst. Engineers and Shipbuilders in Scotland, 22nd November. 1892.

cubic-foot in the solid. It did not cube well in the stone-crusher, and, had it been practicable, should have been broken by hand. The amount of grit resulting from the crushing was 1·66 per cent. of the bulk of broken stone; and, supposing the slag at Newport produced three times this amount, the composition of the concrete mentioned in the first trial at Newport would be as follows, according to the method adopted by Mr. J. Watt Sandeman in his Paper on Portland Cement Concrete :—[1] Mr. Bell

	Parts.
Slag	100·0
Sand	38·3
Cement	13·3

i.e., 151·6 parts of dry material to form 100 parts of set concrete, or 33·38 cubic-feet to form 22 cubic-feet of concrete. Supposing the percentage of interstices of the broken slag were as low as 34, this would not give a sound concrete, as there would not be sufficient mortar to keep the pieces of slag apart. At Emu Bay the interstices of the broken basalt (machine-crushed, $2\frac{1}{2}$-inch gauge), were 44 per cent., and for a concrete of 1 of cement to $2\frac{1}{2}$ of sand the writer would have adopted the following proportions: 10 per cent. would be taken from the bulk of the stone and added to that of the sand (or mortar), to provide a matrix of mortar round each stone, this giving in 100 parts of concrete :—

	Parts.
Stone	90·00
Sand	49·60
Cement	19·84

i.e., 159·44 parts of dry material for 100 parts of concrete, or 35 cubic-feet of dry material to form 22 cubic-feet of concrete. That was without taking into account the shrinkage in mixing and setting. In like manner, a 1 to 1, and a 1 to 3 concrete at Emu Bay would require about 34 cubic-feet of dry material to 22 cubic-feet of concrete—more than one-half the cement in the richer concrete replacing its own bulk of sand. He had experienced no trouble from painting the moulds with a wash of soft soap. To fix the concrete particles and present a smooth surface to the wash of the sea, he had painted the surface of 25-ton concrete blocks with a wash of neat Portland cement immediately after removing the moulds. This effectually stopped any small interstices in the skin of the concrete. It was noticeable that in the Newport dock and in several other recent works recourse was had to rollers to support the gates. He would like to hear the reason for this, as for many

[1] Minutes of Proceedings Inst. C.E., vol. liv. pp. 251 *et seq.*

Mr. Bell. years their use has been dispensed with by Messrs. Bell and Miller. In the case of Messrs. Lopez and Company's dock at Cadiz, built by them, the gates worked successfully without rollers, each leaf being 37 feet in breadth and weighing 80 tons. Air-slaking of cement might be overdone, although he had used Portland cement successfully in submarine work after it had been stored in barrels for two years; as sluggish cement was a source of anxiety and might in certain situations endanger the work. He strongly approved of the 7-day tensile tests for cement being, in the absence of 28-day tests, kept low, as in the Belfast and Newport specifications, and his experience of cement bought in the open market was that the residue on the 2,500-mesh sieve might be specified lower than 10 per cent. With regard to the Messent mixer, he had found it essential not to run the mixer at such a speed as to keep the sand sticking in the corners. With the use of damp sand, great trouble was experienced unless this was attended to, and from the same cause it was more necessary to give a sufficiency of water to a damp sand than to a sand which was dry and incohesive.

Mr. Cay Mr. W. Dyce Cay thought a short account of a work completed by him in 1887, in restoring the dock-entrance at Arbroath harbour in a quicksand foundation, might be of interest. The water impounded in the dock at a high tide, aided probably by deepening-works in the neighbourhood of the entrance, had forced its way under the sill and side-walls, and scoured out the sand foundation, so that the masonry sank into the sand to between 12 and 16 feet below low-water. To restore the works, he had first surrounded the site on all sides by a cofferdam of a single row of 11-inch sheet-piling, by means of which, when the water was pumped out, the greater part of the ruins were excavated. When nearly all removed, however, there was a dangerous "blow" of water, owing to imperfections in the cofferdam, and the rest of the excavation was effected by divers and a steam-digger. A layer between 5 feet and 11 feet in thickness of clay-puddle was then deposited all over the pit, through which bearing-piles 10 inches square were driven, 4 feet from centre to centre, and two rows of 9-inch sheet-piling with a 7-feet space between them were carried transversely across the work under the sill and side-walls—all this piling being cut off at a level of 3 inches above the top of the clay by divers. A sheet of jute-cloth was then spread over the entire surface and up the side-walls of the dam, and a depth of 3 to 8 feet of concrete was deposited on it, lowered through the water in a skip; a tongue or cofferdam of concrete, 7 feet thick,

being carried down 5 feet below the rest, between the rows of sheet-piling and reaching 11½ feet below the sill, all being laid under water. When the concrete had set for about a month the water was pumped out of the dam by large centrifugal pumps, and, the concrete being found to be hard, the sill, invert and side-walls were built on it by tide work, the water being allowed to flow over it at high-water, and being quickly pumped out during the ebb. The concrete used for deposit under water was gauged 7 of sand, gravel and broken stone to 1 of Portland cement, and it was mixed by steam-machinery. When the Portland cement was tested on delivery, 93 per cent. of it passed through a sieve of 5,800 meshes per square-inch, and its tensile strength with the grit sifted out, when mixed with 3 parts by weight of sand, was 205 lbs. per square-inch, the briquettes being 1 square-inch in section, kept one day in air and 27 days under water. Mr. Cay.

Mr. C. H. Colson desired to know what measures were taken at the Halifax graving-dock to prevent the accumulation of water between the concrete and rock, also the nature of the keying or other attachment of the concrete to the rock. In a large number of experiments recently under his notice, the interstices in hand-picked stone amounted to 50 per cent. of the gross bulk. Other experiments showed that 1 part of cement to 2 of sand gave an average of 2·36 parts of mortar. Well-punned concrete had been subjected, in slabs 1 foot 6 inches thick, to a hydrostatic pressure of 30 lbs. per square-inch for 2 hours without showing leakage. He had found white-wash answer well for coating concrete-moulds used in face-work. Mr. Colson.

Mr. J. Bruce Crawfurd contributed the following notes on the construction of the No. 2 graving-dock for the Mercantile Dry Dock Company at Jarrow-on-Tyne. The ground upon which the dock was founded consisted of fairly stiff clay, but there existed, at a depth of about 12 feet below the dock bottom at the lower end and very close to it at the upper end a bed of several feet of soft silt. Experience gained during the construction of No. 1 dock showed that the greatest caution would be necessary to guard against the risk of the soft material bursting up through the comparatively thin crust of firm clay, which would be left over it when the foundations were taken down to their full depth. It was therefore decided to excavate in as small areas as possible. The side-walls were put in first in trenches, timbered and excavated in the first place only as far down as the level of the top of the dock-floor, or 8 feet above the foundation of the walls. When a length of trench had been excavated, a pit, of the full width Mr. Crawfurd.

Mr. Crawfurd. of the trench, 16 feet, but not more than 10 feet broad, was sunk to the bottom of the wall without timbering and concreted, then another beside it, and so on—never exposing more than 160 square-feet of foundation at a time. This method, whilst effecting economy in timber and being safer for the work, had the advantage of allowing the clay on the inside of the trenches to be cut so as to form a skewback for the abutment of the floor-invert against the walls. At Newport, the concrete at the base of the walls had to be cut away for this purpose; whilst at Belfast the skewback appeared to have been formed by placing boarding at the proper angle at the bottom of the trench. As the side-walls were brought up and the strutting in the trenches was removed, every strut taken out was replaced by a short strut from the face of the wall to the walings on the inside of the trench against the dumpling. This prevented any possibility of movement in the walls until the floor was put in. When the side-walls were nearly joined at the top of the dock, the floor was commenced at about the centre, by cutting a trench across from wall to wall with slopes as steep as would stand down to the level of the top of the dock floor, which was 10 feet thick in the centre. A centre pit, 10 feet square, was then sunk to the bottom and concreted, then two pits, one on each side, and, lastly, two more on each of these again, completed a 10-foot band of floor between the skewbacks at the bases of the walls. The sides of the pits were cut radial to the curve of the invert. While one 10-foot band was being concreted, the dumpling, which was maintained at the coping-level as long as possible, was being cut down for another 10-foot band. At no point in the floor was a larger area than 100 square-feet of foundation exposed at one time. Owing to these precautions, the work was carried out without accident. The dock was entirely of concrete, excepting the hollow quoins and sill beams, which were of greenheart. It was commenced in January 1891 and opened on the 4th August, 1892, and was under his charge for the engineers, Messrs. Sandeman and Moncrieff, of Newcastle.

Mr. Doherty. Mr. William J. Doherty remarked that the cofferdam at the Halifax dock seemed to have been successful, but greater interest would have been added to the description of this part of the work had the Author given the cross section and base of the puddle wall. The proportion of cement used was not excessive, as concrete gauged less than 6 to 1 was rarely capable of preventing the infiltration of water. The description of the jetties, extending out into 30 feet depth of water, with piles driven "into the rock

débris," was not quite clear. The Author recorded another instance of the uselessness of "plastering" the surface of concrete for appearance' sake. In reference to the making of concrete, he considered that "punning" it as puddle was punned was a mistake. Concrete, if well mixed with a full supply of water and deposited under the treading operation of the men who arranged it in place against the casings, received quite enough manipulation. Mr. Doherty.

The only drawback to the "trench system," as carried out at the Alexandra dock, Belfast, was that the trench might have been made wider with advantage. "Blows," charged with water, clay or sand, were unavoidable occurrences in deep foundations when supported with timber; and the best way to prevent "the pores of the concrete" from being filled was to leave no pores to fill. When the concrete work had been actually commenced, and when the "boils" described by the Author began to make their appearance, he had been called in by the contractors to examine the foundations and report to them on the subject. The excavations consisted of silt and blue clay to about 17 feet below datum, when about 1 foot of fibrous laminated peat was passed through, then a bed of 3 feet 6 inches of gray sand, lying on red sand, in which the foundations were laid after excavating about 18 inches through it. The features of this fine red sand were that it was a water-bearing stratum communicating with the river wherever its outcrop occurred, and gave all the trouble generally experienced by engineers when dealing with such formations. Similar "boils," derived from a like bed of red sand, were met with in the construction of the Hamilton graving-dock at Belfast, executed by him in 1866; but the pressure from the river in the case of the Alexandra dock was greater owing to its greater depth. In the case of the Alexandra dock, the writer was of opinion, as stated in his report to the contractors, "that the clay bed, if within reasonable distance, should be reached," and quite concurred in the remedies suggested by Messrs. Hawkshaw and Hayter.

Mr. John Kyle expressed surprise at the various failures in concrete alleged to be due to the action of the sea after a certain lapse of time, especially in the case of the graving-dock at Belfast. During his experience of constructing concrete works in fresh and in salt water, he had never found the cement give way in the manner described. Provided the cement was of the best quality, he held that failures under the action of salt water were entirely due to improper manipulation during construction. If contractors would, when constructing concrete work, sink one or more Mr. Kyle.

Mr Kyle. sumps to, say, a depth of 6 feet below the lowest trench-bottom, and lead the surface-waters thereto, maintaining these until the completion of the work, there would be an end of the troubles so frequently complained of. At the Colombo harbour works he had superintended the construction in Portland cement concrete of over 200,000 cubic-yards of blocks, bag- and mass-work, all of which was gauged with and set in sea-water. Although those works were twelve years under construction, he never saw the slightest signs of disintegration or softening of the material either on land, or after immersion and exposure to the seas of a south-west monsoon. The cement was stored there in barrels between 3 and 12 months before being used. During the construction of the Manchester Ship Canal he had superintended the making and setting of over 500,000 cubic-yards of Portland cement concrete in wet docks, locks, and sluices, without the slightest failure in the material; and this he attributed to the method of execution of the works. The walls and other works were built in trenches, like those at Belfast, with this addition, that in each dock-bay, and in lengths of the wall, a 12 feet by 12 feet sump was sunk 6 feet to 10 feet below the trench-bottom, alongside; but clear of the trench. When a section of the foundation was ready to build upon, a chase was cut in the bottom and a 6-inch drain-pipe inserted and led into the sump, and so on as the work proceeded throughout the entire 5 miles of trench work. These pipes remained in the permanent work, and the pumps continued in operation until the water was admitted to the docks, some year or more after the concrete had been deposited.

In making concrete, the following points should be specially attended to:—Water should never be added after a thick, firm, pasty condition had been attained in the banker. If made by hand the banker should contain, say, 20 cubic-feet turned twice dry and three times wet. The concrete should be deposited in layers not exceeding 18 inches in thickness, carried the full breadth of the wall. Before adding a fresh layer, the surface should be thoroughly doused with clean water and swept down with a hard brush. No concrete should be dropped into position from a greater height than 6 feet, nor should it be made or deposited in frosty weather. In the case of work being stopped by frost, the concrete should be closely covered with mats or straw. Should the frost in any degree affect the skin of the work, it should be swept off and left clean. Before using cement, care should be taken to aerate and cool it thoroughly. If cement were bulked 3 feet deep and kept for 4 or 5 weeks before being used,

no further treatment would be necessary to give satisfactory results. Mr. Kyle.

Mr. Daniel Macalister thought some account of the San Fernando graving-dock, near Buenos Ayres, which had cast-iron meeting-faces on the sill and vertical quoins, might be of interest. The entrance was 64 feet in width, the depth from coping to sill 18 feet 2 inches, and the depth of water on the sill at high-water of normal spring-tides 13 feet, but the tidal range was very variable. The gates were capable of excluding the water to coping-level and of working then, and also when there was only 5 feet of water on the sill—the ordinary low-water level. Owing to the absence of suitable stone and the expense of skilled labour, he had decided to make the meeting-faces of the sill and vertical quoins of cast-iron, and to simplify the work at the "hollow quoins" by substituting for the heel-posts of the gates adjustable brass-faced cast-iron heel-blocks, and, for the hollow quoins, cast-iron thrust blocks built into the brick-work, with brass faces against which the brass faces of the adjustable heel-blocks of the gates worked. Mr. Macalister.

In order to avoid making the water-tight joint at the hollow quoins, the method described by Mr. Hayter[1] was adopted, and the joint was made on the plane faces of the vertical cast-iron quoins. The dock entrance was constructed of brick-work and Portland cement concrete in the ordinary manner. The cast-iron sill or meeting-face was made in sections, bolted together and built into the brick-work. The cast-iron vertical quoins were similarly built in, and were bolted at the bottom to the end-pieces of the cast-iron sill meeting-face. The thrust-blocks (substituted for the hollow quoins) were connected by cast-iron distance-pieces to the sill and vertical quoins. The pivot-castings were bolted to the bottom of the thrust-blocks and the ends of the cast-iron roller-paths were bolted to the sill; so that the whole were connected together, an arrangement which greatly facilitated their erection and helped to ensure accuracy.

The gates were constructed of wrought-iron with teak mitre-posts and meeting-faces. The lower portions consisted of tanks of such capacity that when the water was at its normal level the gates were almost floating and could be opened and shut with ease. But as the gates had sometimes to be opened with only 5 feet of water on the sill, the displacement was then considerably less, and rollers had been provided to take the excess weight.

[1] Minutes of Proceedings Inst. C.E., vol. lv. p. 73.

Mr. Macalister. Each gate consisted of 4 horizontal girders connected by vertical box-girders, or man-hole trunks, and by intermediate bracing; and the horizontal stresses were transmitted from the 4 adjustable heel-blocks on the gate to the thrust-blocks built in the masonry. The pressure on the brasses of these thrust-blocks when the water was level with the top of the gates was less than 1 ton per square-inch, and then the pressure exerted on the brickwork by the thrust-blocks did not exceed 5 tons per square-foot; the pressure at normal water-level being about 50 per cent. less.

The adjustable heel-blocks consisted of castings bolted to the heel-ends of the gates, with brass-faced blocks which could be moved out or in by means of tapered keys or wedges. After the gates were erected in position, the blocks were tightened up until a perfectly close joint was obtained at the mitre-posts. The contractors for the gates and ironwork were Messrs. Kincaid and Co., Greenock, N.B. The difficulty of securing water-tight joints at hollow quoins and mitre-posts was well-known; but, by making the joint at the heel of the gate on a plane surface, the water-tight joint at the hollow quoins was avoided, and by the adoption of adjustable heel-blocks the difficulty at the mitre-posts was considerably reduced.

Mr. Mackenzie. Mr. J. B. Mackenzie observed that the site of the Biloela dock was chosen on account of the Fitzroy dock (made by convict labour in 1853), engineering workshops, and other accessories of a dock establishment, being situated on the island. In the Appendix to the Paper on that dock it was stated that "air slaking was dispensed with in the case of concrete deposited under water, as it was considered that the extra slowness with which the concrete set gave ample time for the thorough slaking of the cement before setting." It was doubtful whether this decision was altogether free from risk, and it was certainly contrary to the general opinion and practice of engineers. It had been considered that any disturbance of concrete after deposit, from whatever cause, was detrimental; that with slaking and setting going on at the same time there would be a serious risk of disturbance; and that it was especially advisable to adopt every precaution in cases of concrete deposited under water, having regard to the difficulty and expense of making good failure in such a situation. The great cost of the dock was chiefly due to the high scale of prices which obtained in the colony at the time the contract was let. A few specimens of prices from the contractors' schedule (the accepted tender being the lowest of fifteen) might be given in illustration of this, viz.:—

Ordinary Labourer	10*s.* per day.	Mr. Mackenzie.
Artizan or mechanic	16*s.* „	
Portland cement	£6 5*s.* per ton.	
Sandstone ashlar (stone found on the site)	3*s.* 6*d.* per cubic-foot.	
Granite ashlar	11*s.* 6*d.* „ „	
Ironbark piles	4*s.* 3*d.* per lineal foot.	
Oregon timber	5*s.* per cubic-foot.	
Wrought-iron	35*s.* per cwt.	
Cast-iron	£15 per ton.	

The report of Messrs. Hawkshaw and Hayter, alluded to in reference to the Belfast dock, referred to sea-water as "continually percolating the concrete," and recommended that "superior rich concrete" should be used in making good the failures, "so as to render the work as impervious as possible." On examining the composition of the defective concrete, it would be seen that, assuming the voids of the aggregate not to exceed 30 per cent. of their total bulk, there was an excess of mortar, and that a large portion of the sand might have been omitted, and the concrete made stronger and less pervious without appreciable extra cost. It would be observed, also, that the specification for cement did not contain a mortar-test, and that the standards for fineness and tensile strength, and the absence of a special test for deformation, might allow an inferior and even dangerous cement to be used. It would be interesting to know whether the Author considered that the proportions of the concrete and the quality of the cement had anything to do with the failures recorded, and to what extent he would modify his specification in the light of the experience gained upon these works. In contrast to the concrete above referred to, was that designed for the Newport dock, described in the fourth Paper. In that case no sand was to be added to the cement and stone-dust, so that one-fourth of any given volume of concrete was to consist of voids. Naturally, such concrete was found "not to be sufficiently water-tight," and 166 per cent. additional mortar was required to make it so. In this Paper reference was made to the application of experiments on concrete beams for the purpose of ascertaining the strength of a dock-floor. In the first place, however, the breaking-weight was incorrect, as it took no account of the weight of the beam itself; and in the second place, a dock-floor was certainly not a case of a "beam resting on supports." If considered as a beam, it must be as one fixed at the ends, the resistance of which was analogous to that of an arch.

Mr. James Mansergh, in reference to the failure of the floor of the Belfast dock, observed that in the opinion of Messrs. Hawkshaw Mr. Mansergh.

Mr. Mansergh. and Hayter the disintegration of the concrete was due to the presence of magnesia in large quantities in the concrete, and that it was derived from the sea-water which was continually percolating the mass. If that were the true cause of the trouble, the way to prevent it in similar works would be by using concrete of such a quality that infiltration of water into it could not take place. He had found in practice that it was not difficult to make concrete, gauged 5 of stone and sand to 1 of cement, practically water-tight. He doubted whether this could be accomplished with lower grade concrete; and to ensure a good result with 5 to 1—First, the materials must be so graduated that when put together they would form a solid conglomerate; Secondly, they must not be separated—the large from the small—by tipping from too great a height into place; Thirdly, they must be mixed with an ample quantity of water; and Fourthly, they must all be perfectly clean. With regard to this last condition, he thought it was very probable that the weak and putty-like layer which had to be removed from the top of the concrete at the Biloela dock might be due to the dirty sand which formed part of the aggregate. Concrete, gauged 5 to 1 as above described, formed of hard grit stone and sand crushed out of the same, weighed 133½ lbs. per cubic-foot. It required at least 170 tons pressure on the square-foot to crush it, and its surface would take a high polish. He believed that concrete of this class would never suffer such damage in sea-water as was recorded in the case of the material of the Alexandra dock at Belfast.

Mr. Olive. Mr. William Thomas Olive stated that the graving-dock belonging to the Clyde Navigation at Govan, Glasgow, upon the construction of which he had been engaged, under Messrs. Bell and Miller, in 1874, did not differ much in design from those of later date. The dimensions of this dock were :—

	Feet.	Inches.
Extreme length on floor	560	0
Breadth between copings	90	6
Width of entrance	72	0
Depth of water on sill	22	0

Owing to the fact that the dock was built in a thick bed of mud and gravel, its foundations were of most substantial character. Resting upon the gravel and sand was an inverted arch of cement concrete, carried under the walls. Then, to form the floor of the dock, an invert of brick-work of ten 4½-inch rings was built on this bed of concrete. Upon this brick-work and concrete invert stood the massive ashlar masonry which formed the floor. The walls of

the dock were built of rubble-backed ashlar sandstone masonry, and were coped with granite, the whole being set in hydraulic cement. Four centrifugal pumps, with fans 5 feet 6 inches in diameter, driven by steam-engines of the direct-acting double-cylinder type, discharged all the water from the dock, about 6,000,000 gallons, in 2 hours. An auxiliary engine pumped all leakage and rain when the main engines were stopped and also worked the accumulator for the capstans and sluices. The two inlet-sluices were 6 feet high and 3 feet 6 inches wide. The entrance-heads stood 9 feet above high water; but the working-platform was only 2 feet 6 inches above high water. This reduced height of platform allowed an abundance of air and light to reach the men working in the dock, whilst the platform itself was only a moderate height above the dock-floor. The working-platform was 30 feet in width, and beyond it there was a retaining-wall, the coping of which actually formed the coping of the dock and was raised to the level of the entrance-heads. Provision was made for another graving-dock alongside (since built) by constructing a cast-iron culvert, 5 feet 6 inches in diameter, round the head of the dock, encased in 14-inch brickwork and founded on concrete. By this arrangement another set of pumps and engines was rendered unnecessary and a saving of £8,000 to £10,000 was effected. A caisson with a teak keel closed the dock, and great difficulty was experienced in obtaining a water-tight joint with the checks. Mr. Olive.

Mr. J. Evelyn Williams was sorry that the actual cost of the Halifax graving-dock was not given; assuming, however, that it did not exceed Mr. Bateman's preliminary estimate of £135,000, the cost per lineal foot of dock was £233, or about 15*s.* 6*d.* per square-yard of its cross-sectional capacity below the level of high water of ordinary spring-tides. The Biloela graving-dock, Sydney, was also built of concrete and masonry upon rock. The total cost of the works was £267,825. Its cost per lineal foot of dock was therefore £440 10*s.*, or about 26*s.* per square-yard of the cross-sectional capacity below high water of ordinary spring-tides. The Alexandra graving-dock, Belfast, was built of concrete and masonry, chiefly upon land reclaimed from the sea, at a cost per lineal foot of £131, exclusive of the entrance-basin, or about 13*s.* 6*d.* per square-yard of its cross-sectional capacity below ordinary high-water level. The concrete graving-dock at Newport appeared to have been constructed on treacherous strata with great care. The cost per lineal foot of dock was £70, or about 10*s.* per square-yard of its cross-sectional capacity below high water Mr. Williams.

Mr. Williams.

of spring-tides. The relative cost of the four graving-docks was therefore approximately as follows:—

	Width of Entrance.	Depth on Sill at High-water Ordinary Spring-Tide.	Cost per Lineal Foot.	Cost per Square Yard of internal Cross Section below High-water.
	Feet.	Feet.	£. s.	s. d.
1. Halifax dock	89½	30	233 0	15 6
2. Biloela „	84	32	440 10	26 0
3. Alexandra dock, Belfast . .	80	25	131 0	13 6
4. Concrete dock, Newport . .	48	21⅔	70 0	10 0

The Biloela dock, considering its comparatively light and irregular structural section, was evidently a very costly work. The two graving-docks out of the Alexandra dock at Hull, with 60 feet and 65 feet entrances respectively, and 21½ feet of water on the sills, cost, including pumping-machinery, £130,800, or about £115 per lineal foot, measuring from the mitre of the gates to the head coping. The pumping-machinery at the Biloela dock discharged 45,360 tons of water in 3½ hours, with a maximum lift of 36 feet. The discharge was therefore 216 tons per minute, and the power required was $\frac{216 \times 2{,}240 \times 36}{33{,}000} = 528$ HP. As the cost of the machinery and buildings was £21,919, the cost per HP. was £41 10*s*. The pumping-machinery at the Alexandra dock, Belfast, discharged 10,000,000 gallons of water in 2½ hours, with a maximum lift of 25 feet. The power required was therefore 518 HP. As the cost of the machinery and buildings was £10,430, the cost per HP. was $\frac{£10{,}430}{518} = £20\ 3s.$, in contrast to £41 10*s*. per HP. at the Biloela dock. The two ship-caissons of the Alexandra dock, Belfast, cost £4,379 10*s*. each, which was about £1 15*s*. per square-foot of dock-entrance. The sliding caisson of the Biloela dock cost £17,140, or about £5 10*s*. per square-foot of dock entrance. The comparatively high cost of this work throughout certainly required some explanation. Two necessary features in a graving-dock were a rigidly dry floor and as much room and light as possible under the vessel, so as to facilitate repairs. The broad altar, about midway down, should be sufficiently wide to walk upon, so as to closely examine the sides of the vessel under repair, and the pumping-power necessary during the construction

of the dock should, instead of being temporary, form part of the permanent machinery afterwards required for drying the dock and for other purposes. Mr. Williams.

Mr. E. W. Young, in reply to the correspondence as to the Biloela dock, desired to explain that air-slaking of the cement used for the under-water concrete of the sea-walls was dispensed with for several reasons. As it was intended to use the sea-wall as a cofferdam, it was as well that it should be as strong and quick-setting as possible. Moderate air-slaking, while not diminishing the strength of concrete after six months or so, did, he believed, reduce the strength in the early stages of the work. When, for the reason stated in the Paper, it was decided to moisten the concrete previous to deposition, it was believed that the more rapid slaking which the concrete underwent by that operation would compensate for the absence of air-slaking, as in the case of the cement mixed and deposited dry for the first lengths of wall constructed; and, in view of the excess of water with which the cement was treated during submergence, and the time, measured by weeks, which elapsed before the concrete hardened, it was considered that the cement would be so thoroughly slaked before the concrete set as to obviate all danger. Again, as large quantities of cement had to be used, the resources of space in the drying-shed would be severely taxed; and, further, it was well to avoid the risk of having to use cement poor or damaged by wet in the shed, to which, without careful inspection, there was a liability. The walls were exposed for months to the air on their inner faces, and remained from the first absolutely water-tight and showed no flaws. It might be added that the concrete forming the contractors' cofferdam, deposited under the same conditions, when examined after being broken up some two years afterwards, seemed perfectly sound. Mr. Young

Mr. W. Redfern Kelly, replying to the correspondence on the Alexandra dock at Belfast, observed, in reference to Mr. Reid Bell's remarks as to the non-efficiency of the puddle wall suggested in the report of Messrs. Hawkshaw and Hayter, that their scheme did provide for the complete isolation of the dock by carrying a puddle wall across the front of the outer apron sill, as well as by carrying the puddle wall round both sides, and the south end, of the dock. With regard to Mr. Bell's statement that "provided the grains of sand were larger than the particles of cement, coarseness was not necessary so long as it was clean and sharp," that view was not borne out by experience, coarse clean sand having been proved to be much better than fine, though clean, sharp sand, for concrete. Fine sand acted as a parasite, so to speak, to the cement, and to Mr. Kelly.

Mr. Kelly. some extent robbed the concrete of its tenacity. With reference to Mr. W. J. Doherty's report, which was furnished to the contractors in 1886, in which he suggested "that the clay bed, if within reasonable distance, should be reached," Mr. Doherty was at that time aware of all the information in the possession of the Harbour Engineer as to the stratification revealed by the borings; and, certainly, the depths represented by the borings as those at which the boulder clay would be encountered were anything but reasonable. He thoroughly concurred in the observations of Mr. Mansergh, and considered that if the four conditions mentioned by that gentleman were insisted upon, the quality and condition of the cement used being placed beyond doubt, and a just medium observed between extravagance and parsimony as to the quantity of that material, a perfectly reliable concrete could be secured for graving-docks, locks, &c., where those works were to be subjected to unbalanced pressure from tidal water, acting through sandy or other water-bearing strata. The desideratum in a case of that kind was impermeability of the material of which the structure was composed. In answer to Mr. J. B. Mackenzie, the failure of the concrete did not appear to be traceable to the quality of the cement, which was similar to that used in the other collateral works embraced under the graving-dock contract and showing no symptoms of failure; and, as regards the proportions of the ingredients, he would in future, for similar works, be inclined to provide for a concrete composed of one part of cement to two of sand and five of broken stone (or of clean beach gravel, free from sand), all dry-bulk measures. It would be better not to rely altogether upon the impermeability of the concrete when laid in sandy or water-bearing strata, but to line the backs of the walls with clay-puddle and the bottom of the concrete floor with a thin layer of asphalt.

22 November, 1892.

HARRISON HAYTER, President,
in the Chair.

The discussion upon the four Papers on Graving-Docks occupied the entire evening.

29 November, 1892.

HARRISON HAYTER, President,
in the Chair.

(*Paper No. 2629.*)

"The Manufacture of Small Arms."

By JOHN RIGBY, M.A., Superintendent of the Royal Small Arms Factory, Enfield.

THE manufacture of small arms presents itself in two aspects: one, as the ancient handicraft in which the deficiency of tools and machines was to some extent compensated by the manual dexterity acquired during a lengthened apprenticeship, and by continued repetition by the same man of one process or set of processes. This, accompanied by minute subdivision of labour, was the method employed until a comparatively recent period at Birmingham, Liège, and elsewhere, for the production of military arms. The other, as the result of the application of mechanical ingenuity to the invention of special machinery, whereby skilled labour is superseded, and the continued reproduction of accurate copies of an original pattern is assured. It is in the latter aspect that the Author intends to present the subject to the Institution. He proposes to touch briefly upon the history of this modern industry, its connection with the State and with Government factories; to illustrate it by the manufacture of the present magazine rifle at Enfield; and to describe some of the special machines used in that factory, and its organization and functions. He wishes to premise that, in any remarks he may make as to the relations between Government departments and private trade or inventors, he expresses only his own opinions, founded upon observations made before he had any official connection with the Government manufacturing establishments, and confirmed by his experience since he has been in charge of one of them, and has had the advantage of both points of view.

ORIGIN OF THE INTERCHANGEABLE SYSTEM.

The credit of originating the interchangeable system, and of applying machine-work to the production of military arms, belongs undoubtedly to the United States. The first steps seem to have

been taken by Eli Whitney, who contracted to supply arms to the U.S. Government about the year 1797, and applied to their manufacture a method of forging their component parts in dies, using gauges to secure uniformity of pattern. Further improvements were made by Hall, of Harper's Ferry, and by Blanchard, of Middlebury, Mass., to whom is attributed the invention of the copying-lathe, and other wood-working machines used for turning and shaping the stocks.

Introduction into England.

The first machine-made and interchangeable small arms introduced into England were the original Colt revolvers,[1] displayed in that section of the Exhibition of 1851 allotted to the United States. The prominence of these weapons was emphasized by the scanty character of the American display in exhibits of a peaceful kind, and gave rise to much satirical comment. Colonel Colt had, however, in his system of manufacture, initiated a reform of immense industrial consequence to America. Similar methods applied subsequently to the sewing-machine, for instance, gave a wonderful development to that industry. Applied to firearms during and after the Confederate War, it developed the Spencer and Henry Repeater Companies, the Sharp Rifle Company, the Smith and Wesson, the Winchester, the Remington, and other factories fully equipped to produce interchangeable arms in large numbers. In 1852 Colonel Colt imported and fitted up a set of his machinery in Pimlico, and executed a contract for revolvers with which the British sailors were armed during the Crimean War. Finding, on the completion of this contract, that no other large orders were forthcoming, he withdrew the machinery and closed the works. One English firm alone applied the lesson then given; Messrs. Deane, Adams and Deane, commenced the manufacture by machinery of the Adams revolver, near London Bridge; and this work was, after the Crimean War, transferred to the London Small Arms Company, who also, about the year 1858, manufactured interchangeable Enfield rifles with American machinery in the factory now occupied by Spratt's biscuit works. The machinery was subsequently removed to Bow, where the company's works now are. The War Office, meanwhile, awakened to the importance

[1] *Vide* Paper read 25th November, 1851, "On the application of Machinery to the manufacture of Rotating Chambered-Breech Fire-Arms, and the peculiarities of those Arms," by Samuel Colt, Col. U.S.A.—Minutes of Proceedings Inst. C.E., vol. xi., pp. 30 *et seq.*

of the American method by the strikes of the London and Birmingham gun-makers during the Crimean War, had sent officers to America and had furnished the Enfield factory with complete machinery for the system in use there. In 1857 the interchangeable manufacture of the Enfield rifle was commenced. The wisdom of this step was soon apparent in the improved character of the work produced and the considerable reduction effected in its cost.

English Gun Trade.

The Birmingham contractors were slow to follow the example thus set, and an immense demand for Enfield rifles for the United States during the Civil War found them quite unprepared. They utterly failed to meet it, and the loss of the military rifle trade with foreign countries may be dated from that time. Recently, almost all European governments have encouraged the establishment of local arms-factories, equipped with labour-saving machines, and no longer depend upon England, Belgium, or the United States for supply. A Turkish order for 500,000 magazine rifles is now being executed by private firms in Germany; and a Russian requisition for the same number is placed in France. Last year the Chilian revolutionists used with success Mannlicher rifles supplied from Austria; and on every hand there is evidence that, in the design and manufacture of military small arms, England has permitted the initiative to be taken by others.

It is of great importance to trace the cause of this. It certainly does not arise from want of skill among English mechanical engineers. More than one firm in Great Britain can produce gun-making machinery of the most complete and advanced type, and large numbers of their machines may be found in European arms-factories. It has not for many years been necessary to go to America for them. Nevertheless, no British manufacturer has succeeded in establishing a foreign trade in military arms, or brought out an original pattern, to compete for the large orders that the general re-armament with magazine rifles of small calibre might have been expected to place on the market. This indicates want of enterprise and want of confidence in their ability to recognize or produce a design sufficiently perfect to compete successfully with those of foreign makers. There appears to be in England something that deters capable inventors and experimenters from attacking these problems. The reward is too uncertain and remote; whilst the cost of experiments is great. The wealthy companies that own the plant for manufacture will risk nothing; but await the action of the Govern-

ment, and depend chiefly for their profit on such share as they can secure of Government contracts.

It is evident, therefore, that the only hope for the trade lies in the assistance it receives from the War Office; and the sole chance for an inventor is to have his ideas adopted for Government service. Here the working of the Patent Act of 1883 is defective. Previous to that time, the Crown could use any and every patented invention without payment; but, when Government contracts were given to private firms, the latter were liable to pay such royalties as the patentee demanded. In 1883 the new Patent Law was passed to encourage invention and to afford protection to inventors. The manner in which it does so is remarkable. It contains a clause setting forth that a patent shall have to all intents the like effect against her Majesty the Queen, her heirs and successors, as it has against a subject; and a following clause giving to officers or authorities administrating any department of the service of the Crown, by themselves, their agents or contractors, the right to use any invention, patented after passing of the Act, for the public service, on terms to be before or after the use thereof agreed on (with the approval of the Treasury) between those officers and the patentee; or, in default of such agreement, on such terms as may be settled by the Treasury after hearing all the parties interested. The patentee, therefore, has to all intents rights against the Crown by the first clause, and no rights at all by the second; but is bound to accept any reward the "officers" may propose (if the Treasury assent); or if he dissent therefrom, to instruct counsel and incur indefinite expense in persuading the Treasury to be more liberal than the administrative officers. It is not wonderful that British inventors avoid fields so evidently barren. England has had to borrow from America and Switzerland the leading features of her magazine rifle, namely, the magazine of Lee and the small calibre and metal-covered bullet of Hebler and Rubini. In the United States, on the other hand, promising inventions find syndicates to promote them, and companies for the manufacture of arms have, in many instances, been very successful.

In one respect the Act of 1883 is favourable to contractors. It enables them to undertake Government work on equal terms, as regards patent rights, with the Government factories. If the rewards given by the Crown in lieu of royalties were adequate and prompt, no complaint would arise on the part of inventors; but inadequate rewards, and these often unduly delayed, force the patentee to recoup himself by charging excessive royalties to the

private trade on articles produced for home or export demand; and, in consequence, competition with foreign manufacturers—already difficult owing to the high rate of wages—is rendered impossible. The fostering care of Government is necessary to keep alive the manufacture of military arms in this country. The experiments and trials required in developing new patterns are costly, and involve the use of special instruments not often found in private factories. The interest of the State in these investigations transcends all private interests, and it is her duty to take the initiative in experiments of this kind. How much is now done by committees or by the staff of the Ordnance factories is not known to the general public, because there are no reports relating to the matter accessible to them. It is very difficult for anyone outside the Government establishments to obtain accurate knowledge of the requirements of the Army and Navy. Great ingenuity and large sums of money are wasted by inventors, that would be saved and probably directed into useful channels, if all the information at the disposal of the War Office (official secrets excepted) were freely accessible to the public. The sale to private manufacturers, of ammunition and components to be used for experimental work, would much aid them in putting their inventions to practical proof. This is practised by the U.S. Government with good results. It would also be of great benefit to manufacturers of arms or ammunition, if a semi-public trial, according to some pre-arranged programme, were accorded to their productions when asked for, even although they were not required for the service. If such a trial established a position of equality for the arm or ammunition submitted with those manufactured for the army, it would open to the maker a profitable trade. There is always a private demand for the most improved pattern of small-arm from the colonies and elsewhere; but the purchasers require proof, before ordering, that the arms or the ammunition is practically as good as that manufactured for Government. At present the firing proof of small arms is regulated by statute, and for a small fee the safety of each arm is tested, and attested by an impressed mark. A certified report from a Government department of a favourable trial of any type of small-arm, as to its accuracy and serviceability, or of any ammunition as to its ballistic properties and stability, &c., would go very far to influence purchasers in placing contracts. Such trials would be an education to inventors and manufacturers, and could not fail to promote improvement in patterns and in workmanship. The State would profit by observing the results obtained, and by having the ideas

of the most active minds brought under their observation and submitted to the crucial test of an adequate trial.

Before proceeding to describe the factory at Enfield Lock, the Author desires to notice some statements that appeared under the signature "Parliamentaire" in the *Times* of February 2nd, 8th, and 9th, 1892, to the effect that the heads of the ordnance factories act unfairly towards contractors and others, in borrowing and using their designs and machines, and in other ways. No contractors for small arms will be found to support such an accusation. On the contrary, they are often assisted by the Royal Small Arms Factory, and admitted to see the labour-saving machines that have been designed there. They are not unfrequently permitted to send their managers and draughtsmen to take a note of the machines and processes; and at times have been furnished with castings, to enable them to reproduce the machines cheaply. Very recently the Author furnished to a Midland manufacturer of swords, a working drawing of the hardening-furnace alluded to later. In fact, every possible facility is afforded to contractors in this way. As a rule, in starting the manufacture of a new pattern of arm, the contractors, before incurring the expense of new machinery, have the advantage of seeing that already in use in the Government factory. In so doing, the latter fulfils one of its most important functions. It should aim at being a model factory—a pioneer of progress in efficiency and economy of manufacture—setting an example to private manufacturers, and aiding them to follow it by freely imparting the information in its possession.

Description of the Enfield Factory.

In January, 1868, Sir Charles Hutton Gregory, in the course of his inaugural address as President of The Institution of Civil Engineers, sketched the progress of the new system of manufacture at Enfield up to that date.[1] The succeeding twenty years witnessed a continuous development of the works, and the additions made to the buildings in the years immediately preceding 1887, when the Author's connection with the factory commenced, were calculated to largely increase their capabilities of production. The buildings, with the exception of the stores and some of the older shops, are single-storey, and have an available floor-space of over 300,000 square feet. They contain machinery capable of turning out 2,000 magazine-rifles weekly, with their bayonets,

[1] Minutes of Proceedings Inst. C.E., vol xxvii., pp. 186 *et seq.*

scabbards, and accessories; also 1,000 spare barrels and 1,000 spare bayonets, 200 cavalry swords or naval cutlasses, 50 lances and boarding-pikes, and 4 or more complete machine-guns. In addition to new work, machine-guns of the Army and Navy are repaired at Enfield. The works are lighted partly by gas made in the factory, and partly by an electric installation, supplying current to 1,400 Edison-Swan lamps, of 27,000 candle-power in the aggregate. The present gas-works produce illuminating-gas only; which is, however, largely used for heating purposes in the blow-pipes of the brazing-tables, and for hardening and tempering steel components. The machinery and dynamos are driven by 16 steam-engines, of 1,050 HP. The buildings are heated throughout by steam, which is also used in several processes. 19 Lancashire boilers are employed, working at 30 lbs. to 80 lbs. pressure per square inch, and 4 boilers for the electric-light engines, working at 140 lbs.

Stores.

There are extensive stores for rough gun stocks, in which they are air-seasoned for two or three years before use; about one million pieces can be thus stored. The stores for metal and miscellaneous material are also commodious. No large number of finished rifles are kept. All are forwarded to Weedon when completed.

Other Buildings.

The factory being more than 1 mile from the nearest town, Waltham Abbey, the War Office built, for the accommodation of their men, a number of cottages on adjoining land; and a church, which was enlarged in 1885 so as to seat four hundred people. A dining-hall, Mechanics' Institute, and Library were provided; also schools, with accommodation for 500 boys, girls and infants. Houses for the Superintendent and other officers attached to the factory have also been erected by the Government, on land near the railway-station. Of late years a large number of two-storey houses, suitable for workmen, have been built within a radius of 1 mile; and many of the higher paid employees own their houses. Freehold sites can be purchased for about £2 per foot of frontage. The system of pensions, to which all workmen were formerly entitled on completing a full term of service, aided to attach the men to the locality; and many of the men now in the works are of the third generation of employees.

General.

The water-power and water-carriage afforded by the Lea and Thames, were doubtless the original causes for locating this industry at Enfield Lock. In 1887 the grindery was still driven by a water-wheel. This has been replaced by steam-power; as, although rarely stopped for want of water, the wheel was liable to become temporarily useless through floods raising the level of the tail-race. The site of the factory possesses a valuable feature in its ranges for experimental and testing purposes. These extend up to 2,000 yards, and are rendered safe by the height and width of the brick butts and the precautions observed in conducting experiments. The extensions of the Royal Gunpowder Factory at Waltham Abbey approach the north end of the small-arms range. Direct communication between the two establishments will probably soon be established.

Classification of Small Arms.

Among the small arms manufactured for military use, rifles and pistols take the first place, but, to complete the subject, "armes blanches," pikes, lances, swords, and bayonets must receive their share of attention. All these weapons are produced at Enfield in considerable numbers. In former times, the manufacture of the hand-gun, the first portable fire-arm used in war, was simple. It consisted of a barrel with a handle or stock, and nothing more, and was fired by means of a touch-hole and slow match, in the same way as the cannon of the period. To this simple weapon were added in time the match-lock, the wheel-lock, and the flint and percussion locks; then the latter combined with breechloading mechanism, and, finally, combined also with the repeating- or magazine-action. In this, its latest development, the number of the parts and their functions and interdependence increase greatly the difficulties of manufacture.

Lee-Metford Rifle Mark I.

Enumeration of the stages through which the various components pass, will show what a serious undertaking is the production of a new pattern of military rifle, interchangeable in all its parts. The British rifle, the Lee-Metford Mark I, as it is officially named, has, including screws and pins, 82 separate parts. In the production of these, 950 different machines are employed; and there are in addition various processes that do not require the

employment of machines. In all, the list of piece-work prices that go to build up a rifle of this pattern is, according to the present subdivision of the work at Enfield, 1,591; but the accessories, such as sight-protector, hand-guard, bayonet and scabbard, oil-bottle, pull-through and marking-disk, increase the number of operations to 1,863. It has been urged, as a defect of this particular arm, that the number of the components is too great. This is not, however, always a safe criticism of a machine. Inventors of fire-arms, as of other machines, often boast the small number of parts in their designs; but when one part fulfils several functions, it may be more difficult to manufacture than several simpler ones, and more apt, should it fail, to disable the whole action.

Materials.

The materials used in modern military arms are steel, wood, iron and brass. The two latter have, however, almost disappeared from the list, and steel of various qualities has taken their places. In the Lee-Metford Mark I, only two iron components survive. Brass is used only in the heel-plate screws, and the plate and screws to receive the regimental number. All the other parts, excepting the butt, fore-end, and hand-guard, which are of walnut, are of steel, either hardened and tempered or used in its ordinary condition as a substitute for the iron formerly employed.

Processes Employed.

The processes to which the materials are subjected are:—as to steel—analysing, testing, forging, rolling, stamping, annealing, drilling, boring, tapping and screwing, milling, turning, shaping, slotting, drifting, brazing, soldering, grinding, filing, polishing, hardening and tempering, blueing and browning; as to iron—forging, turning, filing, screwing and casehardening; as to brass—casting, rolling, drawing, filing, turning, punching, screw-cutting and polishing; as to wood—seasoning, turning, machining, boring, filing, oiling and polishing.

The Barrel.

In the rifle, the barrel occupies the first place, and has always engaged the special attention of gun-makers. It is the part of the arm that, with its breech-closing mechanism, has undergone the greatest changes in pattern, material, and method of manufacture. Up to the time of the Crimean War, it was, for the bulk

of our troops, a comparatively rude tube of iron, lap-welded under rolls, and tapering externally, with a cylindrical bore of about $\frac{3}{4}$ inch in diameter. Nothing could be more primitive than the muskets and ammunition with which Waterloo and all the great Indian campaigns were fought, unless it be the cannon which Nelson used at Trafalgar. It is true that there were two British regiments armed with rifles early in the present century; but the range of their rifles did not exceed that of the musket, and loading was so slow a process that it neutralized, in the estimation of military men, any advantage promised by their superior directive accuracy.

Magazine-Rifle Barrel.

Very different is the barrel of the present day rifle. A steel tube of accurate workmanship, only $\frac{3}{10}$ inch in diameter of bore, almost perfectly true and straight, rifled to $\frac{1}{2\cdot000}$ inch, and so closely inspected that the most minute grey or seam in the bore, requiring a highly-practised eye for its detection, is considered sufficient to condemn it. The steel used is mild, containing between 0·395 per cent. and 0·45 per cent. of carbon. It may be Siemens-Martin, or crucible, steel; the Author prefers the latter, as giving rise to less waste. It is supplied to Enfield by the maker in solid round bars, $1\frac{3}{8}$ inch diameter and $15\frac{1}{2}$ inches long. Samples are analysed and submitted to tensile tests, but the manner in which the material works in drilling and turning are the tests upon which most reliance is placed. Some steels that satisfy the chemical and tensile tests are not adapted for being worked by the machines. The softest steel is not the best for drilling, but homogeneity is important; freedom from veins and from hard points or pins is indispensable. For example, among samples recently experimented upon was a nickel steel, possessed of remarkable tensile qualities and very clear, but so destructive to tools as to be almost unworkable.

The first operation on the bars is to pass them through the rolling-mill. This is arranged to draw them to their full length, and at the same time to give them the external taper form at a single heat. Ten pairs of rolls working tandem are employed, and about thirty seconds are occupied by the process with each bar; but, as they follow each other through the rolls as rapidly as they can be supplied from the furnaces in which they are heated, it is evident that the capacity of the machine is very large. The plant at Enfield consists of two machines, each having ten pairs of rolls. Each is fed by two furnaces, one on each side, in which

the bars are brought to the requisite heat. The reduction of temperature during their passage through the rolls is small, owing to the considerable amount of work done upon them in the process.

Figs. 1, Plate 6, show the general arrangement of the machine. The pairs of rolls are alternately in horizontal and perpendicular planes. In Fig. 2 the longitudinal section of the bar as it passes each pair of rolls is shown. One of the rolling-machines now in use at Enfield is the first of the kind made. It was designed by a former manager, Mr. Perry, and was manufactured by Messrs. Greenwood and Batley of Leeds. The other, which is that illustrated in Fig. 1, was supplied in 1890 by the same firm, and possesses certain improvements of detail suggested by their experience in making similar machines for foreign factories. The advantage of rolling barrels by this method is obvious, as the forging is completely effected at a single heat. It is proved by testing the steel before and after rolling. In some large manufactories abroad the barrels are forged between dies under Ryder machines or wooden beam-hammers. This is done to enable projections to be formed for the seats of the sights; and, in some patterns, the bayonet is attached to the barrel by means of dovetail pieces so forged on.

When, however, the pattern of the barrel permits it, the rolling machine should be used; as it is found that barrels forged as at Enfield at a single heat, and by the symmetrically-applied pressure of rolls, retain their straightness when heated and during the operations of drilling and turning, better than those that have been drawn down under the hammer. It has not, so far, been thought advisable to temper or stiffen rifle-barrels in this country, but it is practised elsewhere, notably in France. The increase of hardness so imparted must however be small, as the bore is finished and rifled after the tempering operation. It has probably been rendered necessary by the use of steel having, in its forged state, a low yielding-point, and by the high pressures developed in the chamber by the explosives used. In such cases the chambers become enlarged during proof, the interior metal condensing without sensible increase of the outer diameter. A slight permanent set of this kind was noticed after proof of the earlier magazine-rifle barrels; and the system was adopted by the Author of proving them with the chambers very slightly (0·003 inch) smaller than the intended size, and subsequently giving them a finishing cut. By this means, perfect uniformity of size is secured, and the chamber undergoes no further enlargement in use.

After leaving the rolling-mill, the bars are taken to the forge and the swell at the breech end is stamped by a steam-hammer to the required shape. They are then straightened cold in special machines, Fig. 3, by putting them through transverse rolls, or rings, three of which are mounted side by side a few inches apart, and revolve at about 150 revolutions per minute. They are driven by cogged wheels on a shaft that passes through the frames. These wheels engage with cogs on the periphery of the three wheels mentioned. The inner one is mounted on a slide that moves its centre out of line of the centres of the two outer rings; it is also slightly inclined to the others. The slide that carries the bearings of the centre ring, is forced aside by the action of a weight and chain that passes round a disk on the screw operating the slide. In this way the pressure requisite to slightly bend the barrel is applied. The latter is gripped first at its thickest end by the rings, and, revolving with them, is fed through automatically, owing to the inclination of the centre ring. The adjustment of the pressure required is effected by the weight; and, in order to further proportion this to the varying thickness of the barrel, the disk, from the periphery of which the chain unwinds, is made of a volute form, reducing the radius as the barrel diminishes in diameter. These machines, designed by Messrs. Greenwood and Batley, work most satisfactorily. To test their straightness, the bars are next spun, resting horizontally on rollers, a pair supporting each extremity, and any further straightening required is effected by hand-hammers. The men are so dexterous that few blows are needed to make the bars spin true on the test-plate. They are passed to the turning- and drilling-machines without annealing. The ends are turned to gauged sizes in a clamp milling-machine; these extremities are the parts worked to in the subsequent operation. The next machine faces the ends. A shallow hole is sunk in each to steady the first cut of the half-round bits that are used for drilling. The drilling-machines are horizontal, and the drills operate from both ends simultaneously. In the centre of the machine, three barrels are gripped axially in holders that turn at nearly 1,000 revolutions per minute. The bits, three at each end, are half-round, and are held with the flat side down, and fed up at the rate of $\frac{1}{4}$ inch per minute. They are accompanied by a capillary brass tube, supplying soap-and-oil emulsion at a pressure of 80 lbs. on the inch. This washes out the "swarth" and cools the cutting-edge. To render the jet more effective for the former purpose, the tube is given a rapid oscillatory movement, by means of a cam on the spindle.

The attendant occasionally strikes the shaft of the drills with a piece of steel to set up vibration and prevent the "swarth" from clogging. The process proceeds continuously until the drills advancing from opposite ends of the bar nearly meet. The drills at one end are then withdrawn, and the others continue to advance until a small disk, about 0·01 inch in thickness, breaks out, and the two holes meet. Three holes, 0·41 inch diameter and 33 inches long, removing 4·35 cubic inches of steel, can be drilled in these machines in an hour; whereas the time occupied in drilling holes 0·26 inch diameter and 30 inches long, removing only 1·60 cubic inch of metal, is about one and a half hour. The tendency of these drills to follow the line of the axis of a revolving bar is one of those curious occurrences in practical mechanics, which may be accounted for after they have been observed, but which no one would predict. Occasionally, through some defect in the steel, a drill wanders from the axial line. When this is observed, through the motion thereby imparted to the drill, the barrel is taken from the machine and set as much as is required to bring the hole true again. To test its truth, a ray of light is made to illuminate the flat bottom of the hole while the barrel slowly revolves. It is very rarely that a bar is rendered waste from bad drilling. Rough boring follows with a three-edged bit, the blade about 4 inches long. The rough external turning is done in self-acting lathes, which give the required curved taper; three of four cutters act simultaneously, following one another. Each produces a long cutting that attests the quality of the metal employed. Opposite, and closely following each cutter, a guide-block supports the barrel. The cutter-holders and corresponding guides are made to recede from or approach the centre simultaneously, by contact with a template fixed to the bed of the lathe.

Barrel-Setting.

The barrels, previous to rough turning, are fairly straight internally, but the removal of the outer metal causes slight inequalities which are corrected by transverse blows of a hammer by the "setters." In all stages, before rifling the straightness of the bore is tested by the eye, and practice enables the barrel-setter to see and locate a curve, and to strike the barrel in the right spot for its removal. This art of barrel-setting is not older than the present century; it was formerly thought very difficult to acquire, and skilful setters earned very high wages. At Enfield it is the

practice to put young men whose sight is good, under training, and it is found that in a few months the majority of them are able to set well. They are then employed upon piece-work. As their pay is dependent upon the barrels passing view, there is no room for careless or bad work. Skilful setters pass all their barrels and earn good wages, whilst the unskilful have their barrels returned again and again. The latter are transferred to some other work—tending machines or the like; the former develop into first-class setters. After middle age the eye generally loses some of the quality necessary for this work, and it is rare to find a man excel in it after that time of life.

Many mechanical devices have been contrived to supersede the simple ray of light laid, as if it were a straight edge, along the surface of the bore; but the eye remains the arbiter of straightness still, and can be relied on for very perfect results. The education of the eye to detect inequalities in a surface, either external or internal, by shading, is of great importance to a mechanic, and is very commonly neglected. The majority of fitters, filers and turners are unaware of the saving of time that results from this method. It is not so applicable to heavy or large work, but in all cases where the work is portable, and can be held or placed in a position to allow the light to glance along it, it is most valuable. Minute deviations from a straight line, that often cannot be detected by the application of a straight edge, are rendered plainly visible to the educated eye by the shading. Gun-barrel makers are generally skilled in shading, and can detect by its means deviations from straightness of an exceedingly minute dimension. The mechanical test in use at Enfield, which is employed by the viewers to ascertain the general straightness of the barrel, has for index a lever or hand. The short end rubs the bore while the barrel is spun upon a stationary mandril, on which it is supported at the breech and the middle of its length. The rubber of the index enters and touches the bore at the muzzle. Consequently, if the bore at that part does not run quite true with the other two points of contact, a reciprocating motion is imparted to the index, and the latter magnifies the motion sufficiently to make a very small movement of the rubber plainly visible. For exhibition, the machine is fitted with a mirror and scale to read to 0·0001 inch; but in the factory, an index showing 0·001 is sufficiently accurate. Spinning a barrel on roller bearings while the light is allowed to pass through it to the eye, is also an aid in viewing. A quite uneducated eye can detect the difference in the appearance of the bores of a straight

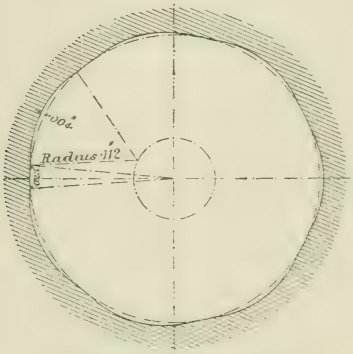
and a crooked barrel when so spun. Before the final setting, the bore is finely finished by passing through it a square bit, two corners of which are kept from touching it by a piece of wood or "spill," flat next to the bit and rounded next to the bore. This supplies the required elasticity, and prevents the bit from tearing, although the action is one of scraping rather than cutting. Oil is the lubricant used; the motion is slow. The material comes away in a fine paste of steel dust and oil, and a smooth and partly burnished surface results. As the wooden "spills" wear, slips of paper are interposed between them and the bit to preserve the necessary tightness. This method of finishing the bore previous to rifling is very old, and has survived newer processes. In France, however, it is now the practice to use for the final regulation of the bore the same kind of machine as for cutting the spiral grooves of the rifling. The cutter, or series of cutters, which, if kept in one track, would plough out a groove, as in rifling, is continuously fed sideways, so as to travel over the whole surface of the bore and remove all inequalities, while it enlarges it to the size required. The barrels, after second turning and fine boring, are externally polished longitudinally in a vertical machine (Fig. 4, Plate 6). This removes all the turning marks.

Rifling.

The rifling adopted for the 0·303 barrel by the Small Arms Committee, under the advice of Mr. W. E. Metford, is shown in section in *Fig. 1.* It is an easily cut pattern, and is found to give good results. Compared with it, *Fig. 2* is the rifling of a poly-groove muzzle-loading rifle of 1845 by Messrs. Wm. & Jno. Rigby, of Dublin—the type of the match and sporting rifle of that period designed for spherical bullets. The French and Germans use a 4-groove section with good results when the ammunition is suitable. *Figs. 3* illustrate four forms of bullet. It is worth while noting here the small depth of rifling which suffices to impart to these bullets a very high velocity of rotation. Some of the explosives tried give a muzzle velocity of 2,250 feet per second; and at this speed the bullet travels along the rifle making one turn in every 10 inches, and consequently receives a rotation of 2,700 revolutions per second. In one of Professor Hebler's rifles a quicker pitch was given to the rifling —one turn in 4·7 inches, and the velocity of rotation of the bullet was about 5,000 revolutions per second. Yet grooving of 0·004 inch in depth is sufficient to impart this velocity with

absolute certainty. The bullet is, however, large enough to fill completely the grooving for about half its length. Accuracy of the grooving in depth and pitch is essential to good shooting, and much care is bestowed upon the rifling to secure this. In British small-arm factories the system of planing out

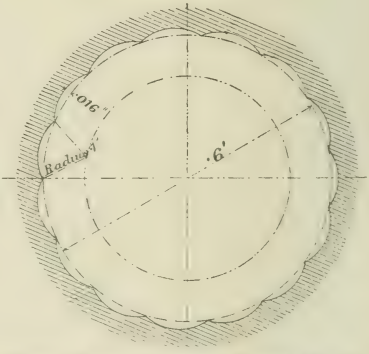
Fig. 1.



LEE-METFORD RIFLE (1888).

Diameter of bore. . . . 0·303 inch.
Depth of rifling . . . . 0·004 ,,
Width of lands . . . . 0·023 ,,
Twist of rifling, 1 turn in 10 inches (left hand).
Radial grooves.

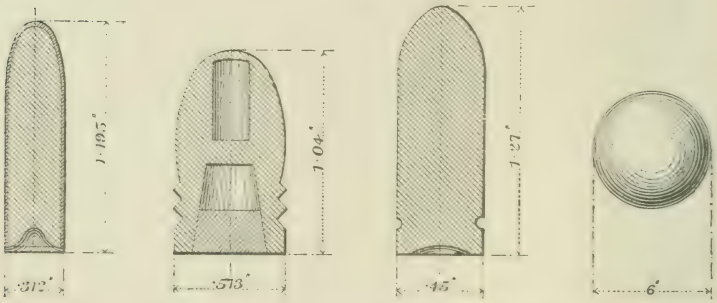
Fig. 2.



RIGBY MUZZLE-LOADING RIFLE (1845).

Diameter of bore. . . 0·600 inch.
Depth of rifling . . . 0·016 ,,
Number of grooves . . 15

Figs. 3.



Resistance of the air varies as the undermentioned numbers :—

2·99. : 4·85. : 2·95. : 7·8.

each groove separately with a hooked cutter is followed, and has been brought almost to perfection, as may be seen by an examination of sectioned and complete barrels shown. A diagram of the cutter and cutter-box is shown in *Fig. 4.* The feed is put on and taken off by the revolution of the screw at the end.

In Continental and American arms-factories, a different system is followed. The grooves are ploughed out by cutters with several cutting- or knife-edges set at an angle and following one another in the manner of a single-cut file or float. The feed is put on and taken off automatically, and the cutter-bar moves rapidly with a light feed. Similar machines have been tried at Enfield, but did not give as perfect and smooth a cut as the slower-moving single-tooth machines. These, with their hooked cutter, attack the metal at the most favourable angle, and bring out a cutting of good thickness, leaving a smooth surface that requires little further finishing. A few passes of a lead lap fed with fine emery remove any burr that may remain and completes the polish. The earliest rifling-machine in Great Britain of which the Author has any knowledge, was designed and constructed by his father about sixty years ago, and was in use until 1862, when it was replaced by one of the type now used at Enfield. This old machine worked on the same system as those mentioned above, which file or float out the grooves rather than plane them. Lapping the bore after rifling, or to renew the surface in case of rust or injury, is effected in the vertical machines (Figs. 5, Plate 6). Five barrels are treated at once. The necessary rotary motion is given to the rods that carry the laps by means of a rack and pinion movement and a guide-bar on which a groove has been cut in the requisite spiral. This first lapping after rifling still leaves the lands of the grooving about 0·001 inch under gauge. A cylindrical lap spinning rapidly is then passed through, and gives the final finish to the lands. The limits of gauging are 0·303 to 0·305.

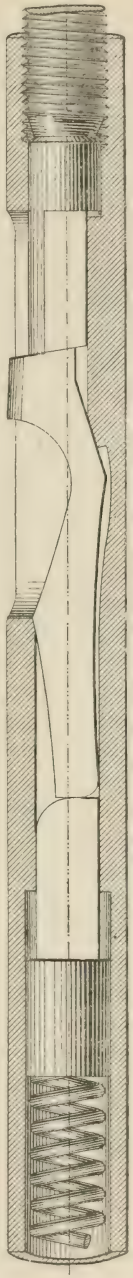


Fig. 4.

CUTTER-BOX OF RIFLING-MACHINE FOR 0·303-INCH BORE.

Twice full size.

Breech-Mechanism.

The breech-loading mechanism comes next in importance to the barrel, and there are few mechanical contrivances that have received more attention than this at the hands of inventors. At all times since the invention of fire-arms, attempts have been made to supersede loading at the muzzle by loading at the breech. The penetrating and destructive character of the flame of ignited gunpowder and the fouling produced by it led to the abandonment of all these attempts until, within the last fifty years, the invention in France of cartridges containing their own ignition and serving as valves to effectually hinder the escape of any gas at the breech, rendered practicable the application of breech-loading to all kinds of fire-arms. Cartridges of this type, drawn or punched up from a solid blank, are now universally employed in military rifles; although, so lately as the Franco-German war, the combatants on both sides used paper cartridges that were not extracted whole after firing, were partly consumed in the gun, and did not entirely prevent escape of gas at the breech. Improved metal and methods of drawing it have popularised the solid-drawn brass case which has now made its way even into artillery of considerable calibre. Generally speaking, the metallic cartridge solves the great difficulty of breech-loading by dispensing with a close joint. It is now sufficient to support the base of the case, so that longitudinal stress may not be thrown on the cartridge-case and cause its fracture. If this is secured, the joint is bridged over by a sufficient thickness of metal to close and seal it effectually. It would be outside the scope of this Paper to trace the various systems of breech-loading military arms. Three strongly contrasted types have been used in our army rifles—viz., the Snider, the Martini, and the Lee. The latter name is not, however, used to designate the pattern of breech-loading, but rather the system of magazine or repetition mechanism. The Lee has, as to its breech-closing, a bolt-action, with many features in common with numbers of other bolt-actions. The details have been worked out to suit the particular cartridge and magazine adopted, and the limiting conditions are compactness and lightness on one side and high stresses on the other, owing to the ballistic efficiency aimed at.

Velocities and Pressures.

A velocity of 1,800 feet per second was first proposed; and it was found, with the explosives then available, that to attain this it was necessary that the bolt should stand a pressure of 18 tons per square inch very suddenly and frequently applied.

Experimentally, higher velocities than this were attained, but with pressures increased in a dangerous degree; and in fact the breech action was only designed to bear a working pressure of 18 tons per square inch—the proof pressure being 24 tons. The invention of Nobel's ballistite and Abel's cordite was a step in advance; as these gave a high velocity, with a marked reduction, not only in the maximum pressure on the bolt-head, but in the percussive application of that pressure which occurred when compressed pellets of black powder were used. With cordite, the pressure rises more gradually than with black powder, and the acceleration of the bullet continues to the muzzle. This may be roughly stated as follows:—

—	Velocity.	Pressure.
	Feet per Second.	Tons per Sq. In.
Compressed black powder .	1,850	18
Cordite	2,050	12

The task of the gunmaker is naturally lightened by this excellent quality of the smokeless explosive; the margin of safety in the magazine rifle is largely increased, the play of the mechanism made more easy, and its life greatly prolonged. It must be borne in mind that portability is of such importance in military small arms, that the dimensions must be restricted so as to keep within the desired weight; whilst, on the other hand, the exceedingly rough usage to which they are subjected demands great strength in all the parts.

Manufacture of the Body.

The material used in the body is steel, and for this purpose the Author prefers a crucible cast-steel of a mild character. It must, however, be suitable for hardening in those parts exposed to the pressure of the bolt. The body is the most important component after the barrel, as it is the frame in which the bolt works.

Into it the magazine is secured, and it forms the connection between the stock and the barrel. It is forged in two operations under the steam-hammer. The second of these completes its form in top and bottom dies. It is then drilled through in machines similar to the barrel-drilling machines already described, and is subjected to a long series of operations before it assumes its final shape and dimensions. In the course of these, the end is recessed to receive the screwed end of the barrel, and the corresponding thread in this recess is milled out in a specially-contrived machine, to ensure that the thread shall always start in the same place relative to the gauged part of the body. It is of great importance that the barrels should all screw up to the same place, and that the distance from the breech face of the barrel to the shoulders that hold up the bolt when closed to its position, should be always the same.

The bolt, forged under the steam hammer, is of crucible cast-steel of a medium temper (carbon about 0·7 per cent.). Top and bottom dies are used to complete its forged shape. Owing to the rib that runs down one side and the opposite lug, it cannot be turned throughout its whole length; automatic shaping-machines are used. These vary the length of stroke as the bolt revolves in the holder, so that the cutter travels over all the cylindrical portion without interruption. A special machine invented at Enfield is used to finish the bolts after shaping. In it they are forced between two stationary cutters that have the required profile, and clasp the bolt. Micrometer-screws diminish the distance between these until the bolt is reduced to the required size and the marks of the shaping cutter are removed. After the machining is finished, the bolts, packed in leather charcoal in iron cases, are heated and hardened by immersion in oil. The temper of the handle is then reduced in a lead bath. The rest of the bolt is tempered straw-colour. The bolt-head is similarly hardened and tempered.

It is unnecessary to enumerate the other components comprised in a complete rifle. For the most part their shape is given either by mills built up to the required profile, or by copy-milling machines, the general type of which is a cutter or small milling-tool on a vertical axis carried by a frame, whose motion relative to the work is controlled by a hard steel rubber, which is constrained to follow the profile of a hardened guide-piece of the exact size and shape of the part that is to be produced. The process of drifting has been used with good results at Enfield, and applied in a much more effective way than is generally the case. Drifting is used to finish all such slots or perforations as have

parallel sides and are not cylindrical. The common practice is to force the drift through the hole by pressure applied behind it, but much better work can be done by pulling it through than by pushing. It is found that, used in this way, drifts are very valuable for interchangeable work. The sides are cut with successive teeth, each slightly larger than the preceding one, and the whole length of the drift is drawn through. Many thousands of holes can be finished in this way by one well-made drift before it needs to be renewed. Another process that has been usefully developed at Enfield is grinding by means of emery wheels, as a substitute for finish-milling and filing. This is largely used in finishing the back-sight leaves and slides, and excellent work can be so produced at a very low cost. The wheels run under hoods, which are connected with a pneumatic exhaust that carries off the heated particles of steel and grit.

It is popularly supposed that a machine once adjusted to turn out a component of a certain size and shape is capable of reproducing such in large numbers, all absolutely identical. This is so far from being the case that it may be said that no die, no drill, and no milling-cutter, actually makes two consecutive articles of the same size. The wear of the cutters or dies proceeds slowly but surely, and it is only possible to produce in large numbers components of dimensions varying between a superior and an inferior limit. The machine is set to turn out pieces at one of these limits, and is kept at work just so long as the altering dimensions remain within their range. It is then reset to the original starting point, and so the production is continued. In small arm manufacture a variation of 0·002 inch is about the amount tolerated. In small components, such as screws and pins, it is much less, and in some large pieces it is more. It is evident that it should not be constant in amount, but should vary in proportion to the size of the piece whose variations are to be measured. For instance, a difference of diameter in the sight-axis hole and in the size of the pin or axis, of 0·002 inch, would cause a serious misfit; whereas a similar difference in the measurement of the magazine, or of the recess in which it lies, would be quite immaterial, so long as the minimum recess were not actually smaller than the maximum magazine. In most of the operations on the components, the machine-tender is provided with hard gauges by which he can check the work; and it is his duty to call the attention of the fitter who is in charge of his section, as soon as the gauge informs him that any readjustment is required. Such adjustments and all tool-sharpenings are done by qualified

men, and as little as possible is left to the machine-hands, as they are not skilled mechanics, but youths and labourers trained to perform the simple duties required. In many instances one man can tend several machines.

Gauging.

A good deal of forethought has to be exercised in laying down a system of gauging for a new pattern. The important dimensions for the efficient working of the mechanism must be ascertained, and gauges made to measure these accurately, relatively, if possible, to three points, technically called the spotting-points. In the body, the hole drilled for the bolt to a gauged size, gives on its axis two of these points. The recess for the guard (being the part of the body furthest from the centre of this hole) is taken as another point, to determine the vertical plane through the axis of the bolt-hole. This governs the position of the slot on the top of the body and the various surfaces that are either parallel or at right-angles to it.

Interchangeability.

In order to ensure interchangeability of components made at different factories, or at different times in the same factory, an Inspecting Officer, appointed by the Director of Artillery, with a staff of viewers, examines and gauges all the components and the completed rifle in certain stages, which are laid down in the specification of the arm. The preparation of the gauges necessary for this work involves serious expense in starting a new pattern; as, in order to keep pace with the manufacture, several sets, all accurately conforming to standards, must be in use at one time for this purpose alone. These require workmanship of a very high class. Most of the components, and all the more important ones, are stamped by the inspection-viewers if found to be correct. They are then returned to the factory, either to be further finished or to be stored until they are issued to the "assemblers," as those workmen are called who, from a set of finished parts, build up the complete rifle. It is then finally viewed as a whole, and, if correct, is packed by the inspection department for issue. It must be understood that, according to the system initiated in 1888, the inspection is independent of the manufacturing department, and their viewers have accommodation apart from the workmen whose productions they have to examine. This was a concession to the

Contractors, who sometimes asserted that viewers appointed by Enfield rejected work that would have been accepted if produced at the Government factory. The result has been a considerable increase in the cost of inspection.

Proof.

Among the duties of the inspection-department are those of proof; these, as carried out at Enfield, are as follows :—

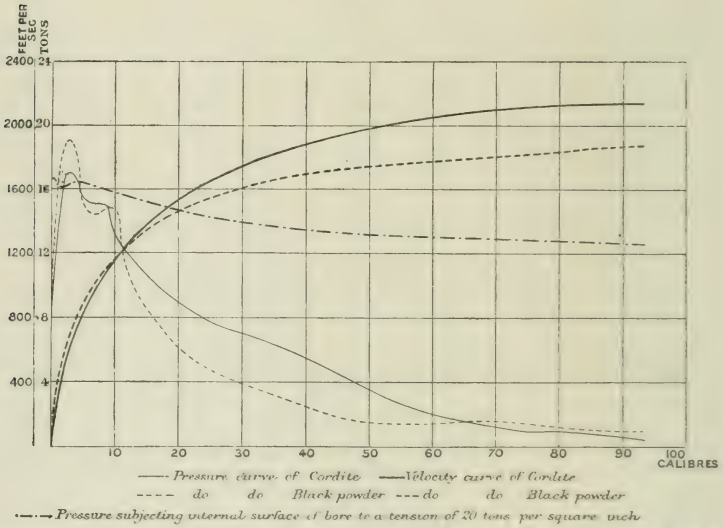
First proof of the barrels before rifling. The breech is closed by a screwed plug with an axial touch-hole; the barrel is loaded from the muzzle with 110 grains of rifle fine-grain powder and a lead cylinder of 350 grains, kept in place by a felt wad; a number of barrels laid side by side in a horizontal frame, are fired simultaneously by a train. Occasionally an unsound barrel is detected by this proof; but the quantity of those burst or bulged is very small—in 1891 the number was only 4, out of 57,000 barrels proved.

Second proof, applied after the barrel has been rifled and the body and bolt assembled to it—a proof of the latter, as well as of the barrel. A cartridge is used with a pellet and bullet calculated to exert a pressure of 24 tons per square inch.

In designing the barrel of the Mark I rifle, some difficulty arose from the fact that the pressure of the smokeless powder that would ultimately be adopted had not been ascertained. With black powder in pellets the pressure of 18 tons per square inch for a little over 1,800 feet per second muzzle velocity was ascertained to be a reasonable estimate, and the barrel was constructed to stand that pressure without injury. In order to ascertain the pressure along the bore, barrels of different lengths were used, and the muzzle velocity was ascertained for each by the chronograph. In this way the acceleration of the shot at different distances from the breech was determined, and the corresponding pressures on the base of the bullet were computed. The curves in *Fig. 5* show the pressure so computed at different parts of the bore for black powder and for cordite respectively. The strength curve shows the radial pressure that would exert a circumferential stress of 20 tons per square inch on the metal around the bore. It will be seen that there is, especially with cordite, an ample margin of strength, particularly in the fore-part of the barrel. A certain excess of strength is required here for the support of the bayonet when fixed, and to prevent the barrel from being bent under rough usage.

A somewhat remarkable instance of the difficulty of obtaining very high pressures with black powder in barrels of 0·303 bore occurred at Enfield two years ago, in the course of an experiment to ascertain the effect of hardening and tempering in diminishing wear and erosion. Barrels in the rifled stage were hardened in oil and reduced to a spring temper. They were tested to ascertain what stress they would endure without bursting. The charges both of lead and powder were increased gradually to 1,700 grains of lead and 220 grains of powder without effect. A charge consisting of 210 grains of powder, a felt wad, an air space of 1 inch, a plug of clay 1 inch, then 2,700 grains weight of bullets, the latter

Fig. 5.



CURVES OF PRESSURE, VELOCITY AND STRENGTH, FOR THE LEE-METFORD RIFLE.

occupying about 15 inches of the bore, was fired. The load was forced forward about 6 inches, but still remained in the barrel. In this state two of the barrels were screwed into bodies and fired with service cartridges in the chamber. One was only bulged; the other burst at the rear of the impediment, but without moving it or affecting the breech mechanism. The burst was caused by a sudden local increase of pressure when the bullet struck the impediment. In the other instance, on opening the breech, the cartridge case was blown out by the imprisoned gas. The body and bolt were uninjured. There is no reason to believe

that the pressure exceeded 30 tons per square inch, except the local pressure in the last trial.

After the second proof, a third is given by firing five service-cartridges from the assembled rifle into a sand butt, for the purpose of ascertaining that the mechanism works properly, and particularly that the feed and extraction are easy. In addition, a limited number of the rifles are fired at 500 yards from a machine-rest, and diagrams are taken to test their accuracy. This test can be carried out at Enfield, where there are well-equipped ranges up to 2,000 yards. The other factories engaged in the manufacture of the Lee-Metford rifle have not facilities for this operation. It is to some extent a trial of the ammunition as well as of the rifles. A barrel is rarely returned to the factory or rejected through failure to pass the required standard. The accuracy of the sighting is not tested by the inspection-department, except by measurement of the various elevations from the axis of the bore. Small differences in the shooting occur that are not attributable to variation in the position or height of the sight. These can only be detected by shooting, and are generally corrected by the soldier after he has discovered them experimentally. They are as often in line as in elevation, and are occasionally due to unequal pressure exercised by the wooden fore-end, where it has become slightly warped. For military purposes they are not of serious importance. The determination of the sighting in new pattern arms, or when a change of ammunition is contemplated, is carried out at Enfield by the factory staff, aided by the range staff, whose services are requisitioned for the purpose when the weather is suitable. The first step taken is to ascertain the muzzle velocity of the ammunition to be used. For this purpose a perfectly sheltered range of 180 feet is used, and a pair of Le Boulengé chronographs. Those at Enfield have been supplied by Pitkin, with improvements in details designed by Capt. Holden, R.A. A secondary battery is employed; and, for the purpose of charging it, a small dynamo is placed in one of the shops. The time of flight from muzzle (across which the wire is led) to a screen, formed of parallel windings of another wire, is ascertained in the usual way by the fall of a magnetically-suspended bar; and the readings of both chronographs are noted. If any discrepancy (outside certain limits) appears in these readings, the observation is repeated. The muzzle velocity is estimated from the time of flight, by assuming that the observed mean velocity is that for 90 feet from the muzzle, and allowing by Bashforth tables the loss of velocity in 90 feet. This cannot

be correctly done until a reduction-coefficient has been determined by experiment; as it is found that the retardation experienced by the projectiles used by Bashforth in his experiments, was much greater than that of the 0·303 bullet—the latter being only six-tenths or seven-tenths of the former. It has been hitherto usual in this country to take the Bashforth tables as applicable to the 0·303 bullet, for the purpose of estimating the muzzle-velocity from the mean. The Author's observations, however, show that this gives an over-estimate of the true muzzle-velocity, amounting to about 20 feet per second. When it is desired to ascertain simultaneously the muzzle-velocity and the pressure at the base of the cartridge, the shots are fired from a form of pressure-gauge that was introduced by General Maitland when Director-General of Ordnance Factories. A Morse cartridge is used, whose base is not attached to the sides, but is free to slide backwards without escape of gas. The pressure is conveyed from the base to the copper by means of an intervening steel plug of small inertia.

Sighting.

Having ascertained the muzzle-velocity, the next step is to ascertain as carefully as possible the effect of "jump," or, as it is sometimes called, the angle of vibration. It is well known that guns, mounted on all descriptions of carriage, move under the influence of recoil before the projectile leaves the muzzle. The effect of this upon the direction is very considerable in small arms, and materially affects the sighting. In the Martini-Henry 0·45-bore and 0·303-bore rifles, it neutralises part of the elevation given to the bore by the sight; in other words, those arms have a negative "jump," and its value must be added to the sighting in order to attain correct results. In rifles like the Lee-Metford, owing to the different distribution of the weights and resistance to recoil, the "jump" is positive, or in aid of the elevation; and this to such an extent that, with black powder, it amounts to 18′, which is more than the angle required to counteract the fall of the bullet under gravity at 200 yards. Consequently, at that range the front sight is higher than the back one, and the barrel is directed towards a point lower on the target than that which it is desired to hit.

The next step in sighting is to ascertain the angles of departure required for the various ranges to which the sights apply. This can be done most conveniently by firing series of shots at each range, the rifle being secured in a machine-rest, and the angles observed

by means of a clinometer inserted in the muzzle; the average of several observations is taken; and the curve so found is compared with one calculated from the Bashforth tables, whence a coefficient is derived, by the use of which the observed and calculated trajectories are reconciled. It is then sufficiently accurate to assume that the coefficient applies to other ranges; and in this way the angle of departure at intermediate and at longer ranges may be calculated. The angles so found are added to or subtracted from the angle of "jump," which connects the shooting from the machine-rest with that in which the recoil is allowed to produce its ordinary effect on the initial direction; the tangents of these angles multiplied by the distance in inches between the fore and back sights, with the height of the fore sight added, give the required heights for the back sight above the axis of the bore. The scale so found is tested by shooting from an ordinary sand-bag rest at some of the ranges. The very high velocities attained in recent years have given rise to various theories as to the manner in which the bullet displaces the air. German physicists have literally thrown light upon this subject by taking instantaneous photographs of the bullets during their flight, by means of the flash produced by the discharge of a Leyden jar. The bullet is found to drive a wave of condensed air before it, and to be followed by a train of vortices. So definite is the conical outline of preceding wave, that the velocity of the bullet may be inferred from the angle of the cone, the higher velocity giving the smaller angle. That these lines of condensation should be rendered visible in these photographs, as well as the outline of a bullet travelling at the rate of 28 miles per minute, is a marvel of photographic art. The aperture and dial sights of the magazine rifle permit an elevation of over 11° to be given, and the calculated range due to this angle is 2,900 yards, with a charge giving 2,000 feet per second muzzle-velocity. Experiments carried on near Lydd in 1889 gave the range with the pellet powder as about 3,500 yards at an angle of 32°.

The Stock.

So far only the barrel, sights and action have been mentioned; the stock also claims attention. This is in two parts, viz., the butt and fore end, the body and the stock-bolt serving to connect the butt with the barrel. This makes the stock stronger than it would be if, like many foreign rifles, it were in one piece, and

had not the stock-bolt to add its strength to that of the wood, where the latter is much cut away to make room for the body and magazine. Walnut, called Italian, although largely grown in other countries, is the wood preferred for the stock. It is not too heavy, is tough and not easily split. The trees chosen for military stocks are those with straight, even grain, and the sap-wood is as suitable for this purpose as the heart-wood. It is lighter, often cleaner in grain, and is rather less liable to warp in seasoning, or after machining, than the heart-wood. Supplies of gun-stocks are obtained from France, Germany, Switzerland and Italy. The trees are felled in autumn, and often cut up in the following year. Steaming is generally applied to hasten the seasoning and remove the sap, which otherwise gives much trouble; causing mildew unless the pieces are frequently wiped over and stacked in airy places. Beech, birch and maple have been used for gun-stocks; and American walnut in the United States; but this is a very inferior wood and easily split. A large store of gun-stocks must be kept, as they require two or three years' seasoning, and are benefited by still longer storage. At Enfield are the stores for supplying stocks to the Government factory at Birmingham, as well as to the companies who have contracts for small arms. The machinery for shaping, &c., the butt and fore end is of American origin, and was designed for the use of the U.S. Government Small Arms Factory at Springfield. Many of the machines at Enfield are those originally obtained from America thirty-five years ago, and they form a collection of ingenious wood-working machinery. The first process is to turn the stocks in self-acting copying-lathes, with cutter-wheels of $6\frac{3}{4}$ inches diameter, run at a speed of 3,250 revolutions per minute. A second turning gives the piece a surface fine enough to leave little for the stock-filer to do. All the recesses to receive the barrel, action, trigger-plate, heel-plate and other parts, are cut out in special machines, the capstan principle with vertical spindles being largely used; jets of compressed-air clear the cutting. The stocking-shop is fitted with a system of exhaust pipes and a fan, by means of which the cuttings are conveyed to the boiler-house, and discharged into a cyclone collector, from which they are removed and fed into the furnaces.

The principal components have now been touched upon. Among the smaller ones, the screws are the most numerous. The admirable automatic screw-making machines of Pratt and Whitney produce these very rapidly; great care is required to keep the tools in perfect order; particularly in the case of steel screws to be

hardened, as they are required to fit tightly and yet to interchange. In drilling the many holes of various sizes that are to be tapped, Morse drills of the exact size required are used, and no subsequent rymering is done. The drills are fluted in the tool-room from bright steel wire drawn to the exact size required perfectly round and straight, and are ready to be hardened without further finishing. The manufacture of the magazine involves a different set of processes from other components. The machines used are presses to cut and bend the sheet steel, and the brazing-table is applied to join up the angles. After brazing, they are passed to the grindery, and the adherent brass and rough edges are rapidly ground off. They are finished by polishing, and finally browned in the same way as the barrel body and other steel parts. Browning is effected by coating the surface with an acid mixture which causes rapid oxidization; the action being hastened by frequent immersion in tanks kept at boiling-point by means of steam-pipes. When a coat of rust is formed, it is brushed off, and the barrel (its ends being closed) is kept in the tank for a time, and is again coated with the browning mixture—eight hours sufficing to produce a black oxide that offers considerable opposition to the formation of rust. Other methods of browning have been proposed, but so far with less success. One ingenious plan of browning by electrolysis was patented about two years ago, a solution of lead oxide being used. The process was rapid, and a beautiful black oxide was formed; but its adhesion to the surface was imperfect, and it was apt to scale off under pressure, leaving the polished surface exposed.

The component-store receives the various finished parts, and these are issued, in sufficient quantity to make a certain number of complete rifles, to the foreman of the assembling-shop. Theoretically, the assemblers should have nothing to do but to fit and screw them together; but small adjustments are found necessary in practice, particularly in parts that are hardened and tempered, as the dimensions alter slightly in these processes. Re-fitting is done wherever possible with the aid of emery-wheels. The amount of correction is generally exceedingly small. The fore end of the stock often requires to be eased in the barrel-groove, as the wood is apt to close or warp slightly. The completed arms are placed in trucks, and delivered into the inspection view-room, which is on the same level, and connected by a bridge with the assembling-shop. The factory sees them no more, as, if passed, they go down a lift into the packing-room underneath, and are issued in cases of twenty each to Weedon or elsewhere.

Swords and Sword-Bayonets.

The production of swords and sword-bayonets is an important branch of Enfield manufacture. The mystery that formerly surrounded sword-making can hardly be said to exist at present; but there is still a good deal of romance connected with it. In Japan it is an art associated with a religious rite, and the fame of illustrious sword-makers survives for generations. Elsewhere in the East, exceptional skill in the manufacture of steel is devoted to the production of sword-blades, and they command high prices. The fame of Toledo blades dates centuries back; but in England, in 1885, when it was decided to renew the cavalry swords, the art was in some danger of dying out, and only one firm in Birmingham was able to undertake a contract, and that in insufficient numbers. In that year, the manufacture was resumed at Enfield on a small scale, but the bulk of the swords required were contracted for in Solingen, where, owing to the large demand for Continental armies, there were manufactories able to turn out large numbers of those weapons. An order for 20,000 swords was given to Messrs. Kirschbaum of Solingen, who had applied machinery to forging blades with great success. Since 1889, all blades made at Enfield have been machine-forged. They are not hammered in any stage after the first rough reduction of the bar under the machine-hammer. The forging is completed by means of segmental rolls, and this method of compressing and drawing the steel produces excellent results. A drawing of the rolling-machine is shown in Figs. 6, Plate 6.

The chief difference between the system now followed at Enfield and former practice is in the hardening and tempering. The blades are heated for hardening in a furnace designed by the present manager, and do not come in contact with the fuel. Figs. 7 show its general arrangement. When sufficiently heated, they are given the required curve by screw-pressure, and are returned to the furnace and brought up to the necessary heat required for hardening in oil. The oil-tank is surrounded by cold water in circulation, and the oil is agitated to assist the rapid and equable conduction of the heat. For tempering, a kind of oven is employed, which is kept at the required heat, and a number of blades are operated on at one time. They are left on the shelves of the oven until they assume the desired colour. In the Solingen manufactory water-hardening is practised, but the steel is much lower in carbon. Their process of hardening and tempering is

kept strictly secret. The blades, although elastic, are not so hard as the Enfield oil-hardened blades. The composition of the steel explains this, the two analyses being as follows :—

English Sword-Steel.		German Sword-Steel.	
Carbon	1·080	Carbon	0·738
Silicon	0·141	Silicon	0·427
Manganese	0·195	Manganese	0·490
Copper	traces	Copper	0·060
Phosphorus	0·002	Phosphorus	0·036
Sulphur	0·020	Sulphur	0·023

In Enfield experience, the requisites for success in sword manufacture are :—(1) A steel of suitable quality, ascertained by trial; (2) forging by pressure with the fewest re-heatings possible, and forging the blade as close to the finished form and dimensions as possible; (3) hardening and tempering in specially designed muffles; (4) giving the necessary curve before hardening, and straightening after tempering without hammering. After grinding, the blades are found to have lost a little of their elasticity. This is restored by heating them to the tempering-colour, and again dipping them in oil—a process known at Enfield as "stiffening."

The tests applied to swords and bayonets by the army inspectors have been the subject of considerable controversy. Manufacturers believed that the bending tests used applied stresses too near to the limit of endurance. Commanding officers, on the other hand, condemned blades for not enduring, uninjured, such stresses as are only likely to occur by accident or unfair treatment. This controversy was brought happily to a termination by the report in 1889 of Sir Frederick Bramwell and Sir Benjamin Baker, made at the request of the Secretary of State. After carefully examining the question, and making several experiments to determine what ratio the stresses applied by the inspection test bore to those that would break or bend a good blade, they demonstrated that this exceeded, in some instances, 60 per cent.; and they were consequently justified in reporting that such stresses applied alternately in opposite directions and several times repeated, must result in destroying the very qualities they were intended to test in the blade. This is an instance of the wide field covered by civil engineering, and is but one of many contributions that those distinguished members of the Institution have made to the scientific construction of military weapons. In addition to the Birmingham firm mentioned above, contracts for sword-

bayonets, swords, and lances, are carried out by the Wilkinson Sword Company at their works at Chelsea. The methods there employed are those of the latest Solingen practice, Messrs. Kirschbaum being interested in the company. A Sheffield firm, Messrs. Sanderson and Co., have also commenced the manufacture of sword-bayonets; so that there now are three contractors for this class of work, in addition to the Enfield establishment, and there is no longer any necessity to look abroad for a supply.

Conclusion.

The Author has, so far, traced the history of the present system of manufacturing military small arms, and has described the Enfield factory, with some account of the processes there applied to the production of the magazine-rifle and sword-bayonet, and of swords generally. He has omitted the consideration of rifle-calibre machine-guns and their mountings, which are also an Enfield manufacture; because these come under a separate category, and would unduly extend this communication. The Paper would, however, be incomplete without some remarks upon the economic features of the Enfield system of manufacture, which is the result of long experience. In the earlier days of the factory, the plan of contracting was chiefly relied on. Almost all the components were contracted for by leading hands, who employed what assistance they thought fit, at such wages as they chose to pay. In this way these hands earned large sums, and something like sweating prevailed. For many years, however, the system in use at present has been followed with success. A strong staff of foremen is employed, and almost all operations have a piece-work price assigned to them. All the employees are rated according to the nature of their employment, at an hourly rate, and are so paid when on time-work. On piece-work they can, on an average, earn about one-third more than their hourly rate. The superintendent is furnished weekly with lists, giving each man's earnings at his piece-work, and the amount that his rate would have given him if at time-work for the same period. These lists enable the superintendent to ascertain whether the prices are fair, and to alter them should he find that the average earnings of all the men on the same operation are unreasonably high or low. In practice, there is not much difficulty in adjusting the prices. The foremen can generally calculate very accurately what time an operation requires, and how many times an expert hand can repeat it in an hour. It is the province

of the foremen, in consultation with and aided by the managers, to devise more expeditious methods and machines to supersede hand-labour as much as possible. When this is done, reductions are made in the prices paid to the workmen, that soon repay the cost of the new appliances; whilst the position of the workman is generally improved, either by increased earnings or reduced labour. All components are gauged by the factory viewers in all the pay-stages of manufacture; and those that are incorrect are not counted to the credit of the workman. The loss of the material spoiled is not, however, deducted, the man only suffering his loss of time. All operations have their piece-work price, and all components are passed through the store in their various stages, and re-issued for the succeeding stage. To illustrate the work necessary to carry on this system, the receipts and issues by the store department have been taken for one week, ending December 19th, 1891:—Number of stages of manufacture, 804; receipts, 809,057; issues, 778,461.

The success of the whole system depends upon a large output. The staff is necessarily expensive, as great vigilance is required to prevent material from being spoiled, and to prevent labour from being wasted on faulty material, and for various other objects. All the costs of staff, administrative and clerical, lighting, heating and power, maintenance of machinery and buildings, stores and depreciation, besides tools of all sorts, gauges, cost of inspection by the factory viewers, costs of store department, work-takers, police, rates and taxes, subscriptions to church and schools, &c., are charged to indirect expenditure, and, as such, are added as a percentage to the direct cost of the production of the year. If the output is large, the burden of indirect charges is spread over it and easily borne; with a restricted output it becomes heavy, and the cost of all articles produced are correspondingly high.

The Paper is illustrated by drawings from which Plate 6 and the *Figs.* in the text have been prepared.

Discussion.

Mr. Hayter. Mr. Harrison Hayter, President, said that in 1860 a Paper was read on the "Construction of Artillery,"[1] which originated one of the most important, interesting, and lively discussions that had ever taken place at the Institution. Among those who had engaged in the discussion were Sir William (now Lord) Armstrong, and the late Sir Joseph Whitworth, who exhibited their own particular forms of gun and described them in detail. The present Paper was very much of the same class, and the Author had exhibited a great many kinds of small arms and appliances. It was true that there were fewer questions to be settled now than had to be settled thirty years ago in connection with weapons of war; but he hoped the discussion would rival in importance and interest that which took place on the occasion he had referred to. He hoped also that it would take a wide range, and embrace not only the manufacture, but also the use in practice and the relative efficiency of the different kinds of small arms. The members had by their applause shown their appreciation of the Author's communication, but he begged to propose formally that their best thanks be tendered to him for his excellent and comprehensive Paper.

Mr. Rigby. Mr. Rigby desired to add a few words in explanation of the diagrams. In place of having the barrel frequently heated and passed through the rolls, Fig. 1, Plate 6, they were passed in half a minute through the whole ten rolls consecutively, and they came out nearly as hot as they went in. The straightening and finishing were effected in the machine, Fig. 3, Plate 6. The cold bar entered the hole shown in the first view, and was caught there by three ring-rollers which compressed and slightly bent it. The centre roller, which was slightly inclined to the other two, fed the bar through, and it came out burnished from end to end, subjected to considerable pressure, and straightened. With regard to bullets, in 1840 he was old enough to remember, although he was but a schoolboy, it was an axiom with rifle-makers that the spherical bullet was the only true form of a projectile. That was only fifty years ago, and was maintained for ten years longer,

[1] Minutes of Proceedings Inst. C.E., vol. xix. p. 283.

since which time there had been an enormous change in opinion upon that point. Another point to which he wished to allude, was the method of rolling sword-blades in segmental rolls. He believed they were first so forged at Solingen, in the manufactory of Messrs. Kirschbaum. The system of forging under the hammer was given up at Enfield in 1889. The rolls were cut away about half the diameter; they revolved continuously in different directions, so that when they were apart the smith was able to take the sword-blade out of the fire, place it in the frame opposite the rolls, and run it out to the end of its course; then the two rolls which were on the surface cut in an eccentric manner gripped the blade and forced it back again, giving it the exact form required before the tempering. There were on the table a few specimens of the multitudinous components to which allusion had been made in the Paper. He also exhibited a series of 30 bolts, showing the operation of manufacture from the forged state to the finished bolt, and likewise a few specimens of the wood-work, from the rough stock to its finished state. Any one who understood working in wood would see that the cutting of the machines and the result as tested by the gauges represented work of a very good character. He also showed a number of gauges which illustrated the critical work required to ensure uniformity and interchangeability in the arms. The foreman from the Small Arms Factory was in attendance, and would be able to demonstrate the manner in which the gauges were used to ascertain the perfection of the pieces. In the library would be found specimens of the barrel-manufacture. Certain of the barrels were cut open, showing the surface produced after rifling. The apparatus was also there, by means of which the eye could distinguish a crooked barrel from a straight one, if it were properly looked through. He likewise exhibited another machine used for testing the absolute straightness of the barrel after it was straightened by the hammer to satisfy the eye. As he had before stated, the eye was used to test the straightness, and the shades thrown through the barrel by a ray of light passing through it were practically the tests applied in regard to those little curves which the barrel got in the course of manufacture. Every barrel, no matter how wrought, would, when a large portion of the outer surface was taken away, assume a new position of equilibrium and take crooks and shades, which had to be rectified by hammering. In order to test them in ordinary practice, the eye was considered sufficient, but a certain number of the barrels were placed in a machine like that exhibited, and tested extremely accurately.

Mr. Rigby.

Mr. Rigby. The barrel was mounted on a mandril, which ran through its whole length, and this mandril was kept by means of a wheel and screw in a state of tension, so as to reduce the curve that it would take by the weight of the barrel. At the breech end there was a bush on the mandril that exactly fitted the bore. In the centre of the bore there was another bush that exactly fitted the bore. The muzzle was un-supported; consequently, if he turned the barrel slowly on those two bushes, and there was any bend in it, the centre of the muzzle would describe a circle round the centre of the mandril. Supposing a straight line to be drawn from the muzzle to the breech, if the barrel was crooked he called the amount that it was out from that line the deflection. There was a rubber which was caused to touch the bore inside the muzzle. A very light spring pressed on that, and it was attached to a mirror which threw a circular reflection on the scale on the wall. It was evident that if a crooked barrel were rotated, the image would travel up and down the scale a distance corresponding to four times the deflection in the centre of the barrel and to the multiplication due to the apparatus. The barrel exhibited was a particularly straight one, because there was scarcely any movement visible as he turned it round. He would now take that barrel out, and put in another that had not been set by the eye. It would be seen that its deflection showed three divisions on the scale, so that the barrel was $\frac{3}{10.000}$ in the centre out of line with the two ends. The Paper professed to deal with the manufacture of small arms, avoiding as far as possible all vexed questions as to pattern and the comparative merits of various systems. The President, however, had expressed a wish that the discussion should not exclude those questions, and a wider field was therefore open for discussion; but he feared that it could hardly be traversed adequately in one evening. Then with reference to the additional expense of inspection on the new system, alluded to on p. 157, he wished it to be understood that it included the cost thrown upon the manufacturers by having to inspect their own work before it was presented for official inspection, and that it was not altogether an increase in the expense of the Army inspection itself. It had also been brought to his notice that he had omitted to mention a small arm which was of some importance in the armament of troops, namely, the revolver. For some years revolvers had not been made at Enfield. The pattern of pistol formerly used in the service, and called the Enfield revolver, was now in a measure obsolete. A different pattern had been adopted, called the Webley revolver, designed

by the firm of Messrs. Webley and Son, of Birmingham, and the War Office had entrusted its manufacture to those gentlemen. Messrs. Webley and Son had equipped their new factory at Birmingham with the best appliances for manufacturing on the interchangeable system; and he had great pleasure in drawing attention to the specimens they had exhibited in another room of parts of the arm, now a service revolver, and also to their seven-piece gauge to which they had to work, and which they considered a very exacting gauge, and a very high test of workmanship. He ought to have mentioned, in connection with the remarks about photographing the flight of a bullet, the name of Professor Boys, whose work in that field was highly appreciated. He had received the President's permission to say a few words about a visit that he had recently paid to three or four of the important arms-manufactories on the Continent. The first was the Imperial Arsenal at Vienna. The manufacturing departments were under great obligations to Colonel Dawson, the military attaché, for the trouble he had taken to obtain from the Minister of War, at Vienna, permission for the deputation to visit the arsenal. In Austria, all arms were manufactured away from Vienna, being sent there from Hungary and from Steyr, where one of the largest manufactories in Europe was situated; and they were there examined, shot, and their interchangeability proved before they were received into the Service. The inspecting staff was not, as in this country, attached to, or located at, the factories themselves. The next visit paid was to Steyr, and it was a very interesting one. Steyr was an old town in Lower Austria, 120 miles from Vienna, possessing fine water-power, two rivers meeting at the town; and the whole valley was full of small mechanics, who for hundreds of years had carried on different kinds of iron-work, such as cutlery and lock-work. There was an ample supply of charcoal in the neighbourhood, which, he thought, partly accounted for their being engaged in that work. Up to 40 years ago they only manufactured and forged parts of guns. At that time a well-known manufacturer in Austria, Mr. Werndl, father of Mr. Werndl, the founder of the present factory, conceived the idea of importing American manufacturing machinery so as to supersede hand-labour; and although he was for some time thwarted in his efforts by the American War and by other matters, he at length succeeded in establishing a machine factory on a comparatively small scale, which had grown into the present large works. They were transferred during the lifetime of his son, the present representative of the family, to a powerful company, the

Mr. Rigby.

Mr. Rigby. president being Baron Tiller, through whose good offices permission was obtained by Colonel Dawson for him to visit the factory. It would occupy too much time to describe the various processes in this factory. There was, however, a certain similarity between them and those at Enfield. He was struck also by the number of different types of machines. It was an old factory, one of the earliest in Europe, and had American, English, and German machines, as well as Austrian. In the forges there was not a steam-hammer. He had been struck abroad by the absence of steam-hammers in arms-manufacture. At Enfield they used them almost exclusively for heavy work; but at Steyr they used drop hammers of different sorts, board-hammers, belt-hammers, and a great many pneumatic hammers of very handy form—a cylinder over the work, something on the model of a steam-hammer, but worked with compressed-air. They used nothing but charcoal as fuel in their forges. That was a very distinctive feature of that factory. It took them two days to see the factories at Steyr. At Letten, 8 miles further up the valley, there was a more modern factory, as far as buildings were concerned, belonging to the same company, where they did forging, barrel-drilling, and part of the heavier milling. Thence he had gone to Berlin, where he was received by Colonel Swaine, the military attaché, who obtained permission to visit the factories of Messrs. Ludwig, Löwe & Co., contractors to the German Government. The Government had four or five manufactories of their own; one at Spandau, which corresponded to the arsenal at Vienna, where the work was viewed, and where they had a small-arms factory; but the Minister of War refused them, in Berlin, the privilege they had received in Vienna, and, consequently, he was unable to visit Spandau. In Berlin, the original works of Messrs. Ludwig, Löwe & Co. were engaged in the manufacture of machinery for making arms and shells, and for various other purposes, such as electrical work. The methods of manufacture and the finish of their work were of the highest order. At that place had been designed most of the machinery in their gun-factory at Moabit, three miles from Berlin, and also in several other modern gun-factories on the Continent. They were in correspondence with, and he believed agents for, Messrs. Pratt and Witney, of the United States, and advocated some of the systems patented by that firm in Europe. From Berlin he went to Liége, and there saw the latest equipped small-arms factory in Europe, and he supposed one of the most complete. It was not a large factory. It was calculated that the output

was, at the outside, 1,000 rifles per week; but it had been inaugurated in a more favourable way than almost any other factory, because it had not grown up by degrees according to the requirements of the owners, but had been built by the present company for a definite purpose; and everything had been designed in accordance with the latest mechanical ideas that obtained in Liége, at all events, and probably on the Continent. The details of the factory would probably, at some time, form the subject of a communication to the Institution; but he might mention one or two points concerning it. The entire shafting was driven by electromotors, and not by direct contact with the engine power. The engine was one of 500 HP., and had been ordered before the Company decided to use electricity for driving the shafting; consequently they were bound to an engine that made 66 revolutions per minute; and they solved the question of generating a sufficient current for their purpose, by converting a fly-wheel, over 15 feet in diameter, into an enormous armature, driven at the rate of 66 revolutions per minute. In that way they had produced one of the finest dynamos in Europe. It distributed the electricity to the ends of the various lines of shafting throughout the building by cable; and for each line of shafting there was a separate motor. Of course the same current supplied light to the building at night. That factory was situated at Herstal, a few miles from Liége. It was a country district; but the people had been accustomed for many years to the process of gun-manufacture, and the Company was consequently able to derive ample labour from the population around, partly prepared for their requirements. It possessed, however, the distinction from other rifle factories—that one-half of the employees were women. At Enfield Lock they had two or three policemen on guard at the gate; but at Herstal there was only one very personable elderly woman in charge. On going in, they found that half the hands were men and half were women. The men worked the heavy machines and the girls and women the light ones. The Company stated that the system worked admirably, and that there was a great saving in wages. The difference, in this respect, was rather startling. He had found at Steyr, where he expected the wages to be low, that the men were earning about 26*s.* per week; whilst at Letten, a few miles away, they were earning about 2*s.* per week less, and at Berlin something more. At all those factories the machines were run by men, and not by youths. That might partly arise from the fact that at the time they were short of work, and had discharged a great number of their hands; but

Mr. Rigby.

Mr. Rigby. they stated that they took no apprentices, and employed no boys, and as few youths as possible. The German educational laws interfere with the labour of boys up to the age of 17, and then the two or three years in which they could devote their whole time to work, brought them to the age when they were obliged to go for military training. That accounted for the preference of the Company to employ men who had passed through such training. The piece-work wages at the Belgium factory came to about 15*s.* per week for men and about 9*s.* for women; or, taking the average, 12*s.* all round, which was about one-half of the wages earned at the same sort of work in Austria and Germany; and less than one-half of those earned in England.

Sir Henry Halford. Sir HENRY HALFORD said that his claim to the attention of the meeting was, that for the last 30 years he had worked with Mr. Metford in all his experiments. The first point to which he wished to draw attention, was the slight praise given by the Author to the Metford method of rifling. He had said that it gave good results, and a little further on, that the French and German systems gave good results with suitable ammunition. Everyone would understand, that if good ammunition were not supplied, good work could not be expected. The Metford rifle was taken by the Government after it had been shown to have won more prizes at Wimbledon than any other, and had proved its distinct superiority over every system tried against it at Enfield. The Author had said that the inventors of the present calibre were Rubini and Hebler. The shape of the present bullet was due to Mr. Metford; but he believed he was right in saying that Colonel Bode, a Swiss officer, first invented the compound bullet—a bullet with a lead core and a metal covering (the inventor used copper) of a harder nature. The point of accuracy, as compared with the system of ascertaining the figure of merit followed by Switzerland and, he believed, by France, should not be overlooked. In taking diagrams for accuracy, 50 per cent. of the shots that went wide laterally were deducted, and 50 per cent. of the vertical shots that went wide, and the accuracy was calculated upon the remaining shots; so that, in the one case, shots which were excluded for vertical error were included in the horizontal diagram, and those which were excluded horizontally were included vertically. The result was that no one knew the absolute value of a rifle fired under those conditions. At Enfield, every single shot was counted. He had official diagrams taken when the accuracy of the rifle was tried there, and, as a rule, fourteen out of fifteen shots struck a 3-foot circle at 1,000 yards,

with proper ammunition. Every effort was being used to obtain smokeless powder reliable not only for accuracy, but for keeping. For a powder was required which would stand the heat of India and the cold of Canada—a very difficult matter. He believed that had been attained; but there was still room for improvement in the accuracy given by the present Cordite powder. They had had other smokeless powders—Nobel's, a powder from the Lee Syndicate, and one or two others, which gave far greater accuracy than the present Cordite powder; but he had been informed that those powders were not so stable, and were not to be prudently trusted by a country like England, which had to keep a large stock of ammunition in store. He had now to make some adverse criticism upon one of the operations in the manufacture of the rifles described in the Paper—the lapping with emery after the barrel had been rifled. Emery was a most valuable substance, properly used, in order to make a perfectly parallel bore before it was rifled. For, before it was rifled, it was possible to view the barrel and see if it was straight, and by gauging it to see whether it had a parallel bore; but the moment a barrel was rifled, it was impossible to get a shade upon it; the rifling interrupted all shading, and it could not be properly gauged with a plug for parallelism, because, in passing a plug down, the rifling so interfered with the sense of touch that it was impossible to say for certain whether the barrel was parallel or not. He felt with Mr. Metford very strongly upon that subject. The cut which Mr. Metford had given to the Government being segmental, the cutter took up a fresh position every time it passed down the bore, and opened up fresh ground, so that the only burr thrown up, on the rifling of the barrel being completed, was that due to the last cut; and, if the tool was in proper cutting order, that burr was exceedingly slight—so slight that five or six rounds fired with the bullets would entirely take it out and render the barrel perfectly true. He had at the present time a Lee-Metford rifle made at Enfield, which had been so scrubbed with emery, that when it came to him it was worn as much as if it had had 3,000 shots fired. He hoped, and had already urged the matter upon the War Office, that this operation of lapping would be absolutely discarded, and that tools alone would be trusted to make a barrel perfect. Who would think of getting up the last stage of a surface-plate with emery?

Sir Henry Halford.

He next wished to refer to the system of reckoning the pressures inside a barrel, which he did not think at all satisfactory. At

Sir Henry Halford.

present, a copper plug was placed behind the cartridge, with a steel plug in front of it. Sometimes, if they wanted pressure further up the barrel, a hole was bored in a cylinder, with the copper and steel plugs arranged so as to take the force of the explosion. The pressure shortened the copper plug, which was then compared with one that had been put under pressure by dead weight, and if it was shortened to the same extent as a plug, by, say, a dead pressure of 15 tons per square inch, that was called a 15-ton pressure on the inside of the barrel. By taking it that way, a pressure developed in $\frac{1}{400}$ second was compared with a pressure developed in five or ten minutes, or whatever time they chose to leave the plug under the weight. That seemed to him an exceedingly rough method of ascertaining pressures. It might be a good comparative method. Where there were two different charges, they could, by comparison, learn something of the relative pressures; but as to calling it a pressure of 15 tons, that was altogether misleading. He said so for this reason: the Small Arms Committee asked for a diagram of the stress which the barrels would sustain before giving way, and a diagram was placed before them which showed that the outside limit of strength for the new barrel was 15 tons per square inch. They were now told that the proof-pressure was 24 tons per square inch. When he was on the committee, they were also informed, from Woolwich, that one barrel had sustained a pressure, according to their way of reckoning, of 54 tons per square inch, with a nitro-powder, which proved unsuitable, but which it was thought desirable to try. It seemed to him, therefore, that there was some error, either in calculating the pressures on the inside of the work, or in calculating the strength of the material. Many officers had asked him how it was possible that so small a bullet could be effective in warfare. He would only refer to the experiments carried out at Enfield with horses, in which they found that the present bullet, from its great velocity, produced as effective a shock as the Martini-Henry bullet with its greater weight and slower velocity. It was well known to all sporting men who used the Express rifle, that speed was a more important factor than weight in a projectile. Beyond a velocity of something like 1,600 feet per second, animal tissue would not stand the blow, and was scattered. As a stone thrown into soft mud would make a hole much bigger than the stone itself, so, after a velocity of 1,600 feet per second had been attained, a large hole was made in the flesh, because the flesh itself became a projectile, and the disturbance was much greater than might be expected.

Sir Edward H. Carbutt considered they might feel satisfied, owing to the action of military men united to that of mechanical engineers like Dr. Anderson and the Author, with the defensive powers of the country; and that, should the necessity arise, they would prove equal to the occasion. When he was in the House of Commons, he had on many occasions criticised the action of the Government, and the Paper fully warranted the action he had taken. He would have been glad to follow the Author in his statement with reference to patentees, because he had sat on the committee on the patent question in 1883. That committee endeavoured to confer a benefit upon the patentee, by allowing him to make a claim on the Government, and expected that the clauses introduced by them would have that effect. He was sorry to hear that it was not so, because it was only right that the patentee should be able to recover something for all the time and trouble that he had devoted to his invention. The Author had said that private firms had not succeeded in maintaining their ability to supply foreign nations as well as Great Britain. He had stated: "Great ingenuity and large sums of money are wasted by inventors, which would be saved and, probably, directed into useful channels, if all the information at the disposal of the War Office (official secrets excepted) were freely accessible to the public." When he was in the House of Commons, his contention for five or six years had been that they could never get any information whatever. All his criticisms had been indiscriminately denied. The information that he obtained came from the United States, where it had gone from this country. By that information he was able to criticise the action of the Government. That was a false position for a Government to be placed in. Instead of being so particular to keep official secrets, they ought to take the manufacturers of the country into their confidence; they would then have the benefit of the mechanical ingenuity of their country, instead of handing it over to America. How was it that America was taking the lead in regard to armour plates and guns? It was simply because they had a commission roaming over Europe, living continually at Woolwich, Newcastle, Manchester, and Sheffield, gaining information about every manufacture of the country. Yet, if the manufacturers of England wanted information from the Government, they could not obtain it. He hoped that the result of the Paper would be to induce the Government to take into their confidence the mechanical, civil, and military engineers of the country; that they might utilize the information at command, and not send it broad-cast to foreign

Sir Edward H. Carbutt.

Sir Edward H. Carbutt. competitors, who would use it against them to compete with them in the private markets of the world.

Dr. Anderson. Dr. W. ANDERSON said that, with regard to the barrels of rifles, there was, as the Author had stated, a difference of opinion as to the relative advantages of forging and of rolling. It was somewhat curious that at the Government small-arms factory at Sparkbrook, Birmingham (to which no allusion had been made in the Paper), the process was to forge the barrels under a Ryder machine, and draw them out in that way. It really might be said to be drawing them out by pressure instead of by blows. But the importance of the difference had yet to be determined in regard to the wear of the barrel, because rifles were now all made for smokeless powder, and that admirable explosive had this disadvantage, that it was so clean that it left no fouling, as black powder did, to act as a lubricant, interposing a film between the bullet and the rifle, and consequently the metal of the bullet and the steel of the barrel were in absolute contact at high velocity and considerable pressure, the result being a rapid wear. The question therefore was which of the two methods of treating steel would prove the best in respect of wear, and that was a very important matter, because, as far as was known, whereas with black powder a rifle would stand some 12,000 rounds, it appeared that with smokeless powder 3,000 or 4,000 rounds would be the limit. In heavy guns the difference of wear would be still more marked. Up to the present, they had only gone as far as 4·7 quick-firing guns for endurance trials, and the wear was distinctly less (that was, there was less erosion or sweeping away of metal by the rush of the powder gases) with smokeless powder than there was with black powder. In a rifle, the rifling at the muzzle end was worn away by the attrition of the bullet against the barrel. In the case of 4·7-inch quick-firing guns, there was not a question of wear, because the number of rounds were comparatively few, but one of erosion. With about 900 rounds, with black powder the steel was washed away, if he might so term it, for a few calibres' length in front of the chamber; whereas, as far as experience went with a like number of rounds, but with very greatly increased ballistics —which meant with a greatly increased muzzle-velocity—the erosion from cordite was comparatively small. But then of two guns that had been subjected to the endurance test, the steel was by different makers, and one gun was wearing exceedingly well, and the other not quite so well. The problem before them, on which Sir Frederick Bramwell and Sir Benjamin Baker would have to exercise their knowledge and experience, was to determine what

it was in the steel—that mysterious compound which claimed so much attention from engineers—that made it wear better in one case than in another. With regard to the pressure-curves, he would ask the Author if the velocity-curve for cordite was not for a higher muzzle-velocity than for black-powder. The Author had described the manner in which the velocities had been obtained by successively reducing the length of the barrel and measuring the velocities at the various lengths. He wished to ask whether any allowance had been made for the increase of velocity imparted to the bullet after it left the barrel, by the rush of gases following it, an increase which Professor Boys appeared to have determined for a barrel of full length to amount to nearly 2 per cent., and which would certainly augment as the barrels became shorter. The Author had stated that it was very difficult for any one outside the Government establishments to obtain accurate knowledge of the requirements of the Army and Navy. He (Dr. Anderson) would go a step farther and say that it was very difficult for any one inside that charmed circle to know those requirements. That need not be a matter of surprise, because much of what was required in warlike stores was at present a matter of conjecture, and nothing but a great war could determine with certainty the relative advantages of the various systems of offence and defence. It was not, therefore, surprising that officers of eminence should hold views which were almost diametrically opposed to each other; that was but the natural consequence of the present state of things, and did not reflect in the least upon these officers. They were merely fallible human beings, and had a perfect right to hold their views, till experience showed where the truth really lay. The Author had certainly started a bold proposition, viz., that the Government should act as a kind of judge, and issue certificates of the value of inventions. He thought the Author must be well aware of the extraordinary difficulty of deciding upon any subject whatever connected with warlike stores. The Small Arms Committee, for example, assembled nine years ago, and had over 30 rifles of 17 different patterns submitted to them by various inventors, and when, after long deliberation, they settled upon a pattern, and some 300 or more were issued to the troops for trial, the result appeared to be so satisfactory that the manufacture was commenced; but no sooner were the actual rifles, Mark I, issued than small defects began to appear. The sights were not quite right, and various other defects became manifest, so that very soon Mark I* rifle was issued with the slight defects remedied, and the rifle was universally acknowledged

Dr. Anderson.

Dr. Anderson. to be a very first-rate weapon, but the military authorities discovered that it would be better to carry 10 cartridges in the magazine rather than 8, and that resulted in another change. Advantage was taken of it to make a few minor improvements, which were embodied in Mark II, the rifle which was now being issued. So that about 9 years had been occupied to evolve, or, to use the term now in vogue, to incubate, that magazine rifle, which he had no hesitation in saying was one of the best, if not the best, in the world. But if the Government were to take upon itself the duty of giving a certificate, stating that a newly-invented warlike-store was fit for service, it would be easy to perceive the length of time, and the expenditure that would have to be incurred to enable such a certificate to be given. He thought, it would be admitted on all hands, that such a procedure was a little beyond the scope of a Government's functions. Sir Edward Carbutt had made remarks which, he confessed, had somewhat surprised him. He had descanted upon the difficulty of obtaining information in this country with respect to warlike stores; remarking that even when he was a Member of Parliament, he was actually obliged to go to America for information. That was extremely likely, because, about 9 years ago, the United States had awakened to the fact that they had neither war-ships nor guns, and they therefore took the wise course of sending to Europe a commission, which visited every factory and every establishment for the manufacture of warlike stores that they could think of. They were well received everywhere, and the fullest information was given to them, and they published a very valuable and interesting report. They then set to work, and began to build ships and to make guns, and they had now actually succeeded in making a 12-inch gun which compared favourably with the old short 12-inch gun of this country; but it was a long way behind the new naval gun that would be issued about next August. That seemed to him to be rather an original way of teaching us gunnery and how to make armour-plates, as Sir Edward Carbutt had said he was sorry to find the Americans were doing. The fact was that they had done nothing for a very long time; they had had the advantage of knowing all that Europe had done in the matter of warlike stores, and they were now coming out with stores, which he did not say were better than those of any European nation, but which ought to be so, because they were produced with the aid of all the experience gained in Europe. With regard to the difficulty of obtaining information, he was certainly much struck with what Sir Edward Carbutt had said; because when

he was himself, not very long ago, a contractor and manufacturer, he never found the least difficulty in borrowing guns from the War Office, and in buying ammunition in order to try mountings which he had contrived. He had also found the War Office then quite willing, as they were now, at the public expense, to try any invention suitable for their needs, and which held out the least promise of success. The charge, he thought, was one that ought not to have been made or entertained. Further, Sir Edward Carbutt must have known that there were handbooks on gunnery, handbooks on small arms, on ammunition, and on almost every subject connected with warlike appliances, which were revised at regular intervals, giving the fullest information. Such books could be bought from any bookseller; in fact, on the title-pages, there was special direction to those who were interested in the subject, as to where the books might be obtained; and, as those books contained all the information considered necessary for the Services, it was only just to infer that it was the information which the general public ought likewise to be content with. The Author had suggested that the Government would do well to make public all investigations which might be useful to outsiders in their efforts to assist the War Office. That was a very old question that had often been debated; but there were several grave reasons against such a course being pursued. In the first place, he did not think that inventors and manufacturers would like it. They would not like to have everything that they brought before the Ordnance Committee, for example, made public in the Proceedings of that Committee; that would be too advantageous to their rivals in trade. Another serious objection was, that if officers entrusted with experiments, or with reports upon various stores and inventions, knew that their statements were to be made public, it would very materially affect the candour of their reports, it would cripple them in a very serious manner, and would serve to conceal from the War Office the exact facts that it was essential for it to know. It was on those grounds that the experiments and reports were confidential, and he hoped they might always be so preserved. With respect to the facilities offered to contractors or others who were interested in warlike stores, he thought there must be many present who would bear his statement out that the Ordnance Factories, at any rate, were always most anxious to afford every possible information. The Author had himself distinctly stated the services he had rendered to the trade, in showing to those who desired it all the various improvements made at the Enfield factory, and the methods by which the

Dr. Anderson.

Dr. Anderson. manufacture there was carried on. The same thing was done in all the factories. Any contractor, or any one interested in any particular manufacture, never applied in vain for information with regard to the mode of carrying on the work, and the machinery used in it, and every facility was always afforded. It was to the interest of the State to give it. The principle upon which the warlike stores were manufactured was that a certain portion only were made in the Royal factories; it had been the deliberate policy of successive Governments to encourage private manufacturers to produce these stores. It was, therefore, one of the duties of the Ordnance factories, and those connected with them, to afford to manufacturers every facility and all the information that they could desire; and he ventured to say that there were manufacturers present who would confirm what he stated, and admit that it was not mere theory, but actual practice. He might mention, in conclusion, a rather curious thing, with which, however, some might be familiar. No matter how skilful the men, and how admirable the materials obtained in the starting of a new manufacture, like that of the magazine rifle, all sorts of strange difficulties arose. They had, for example, a great deal of trouble with the main-spring, which urged the striker forward to strike the percussion cap. Those springs would break; and it was a long time before they found out the exact method of making a spring and tempering it so as to prevent the occurrence of that accident. The same thing happened with the oblong spiral magazine-spring which, in the original rifle, lifted the cartridges to the barrel for loading. They had endless trouble in the first instance, but that likewise gradually vanished. He did not care who was appealed to—an individual or a committee of experts—it was quite impossible to say beforehand with certainty that any article would be fit for warlike purposes. In the case of the rifle, some 300 or 350 were issued at first, and the reports were most satisfactory; but, when the rifle was placed in large numbers, into the hands of the troops, a somewhat different state of affairs appeared, and defects which had not before been suspected —slight ones, but still defects—began to appear. Again, many millions of rounds of ammunition, now known as "Mark I," were made, inspected and passed, and seemed absolutely satisfactory; but when it was issued to the troops, after a short time they began to hear of the bullet misbehaving itself, and the consequence was that a large amount of ammunition had to be rejected. He had therefore come to the conclusion, from that and similar experiences, never to believe in the efficiency of any warlike

store, until after it had been issued to the troops, and had been for some time subjected to the rough usage which was incidental to the service and to the class of men who had to use the weapons, with satisfactory results. Both the manufacturing and the Government departments had been greatly criticised and abused. He supposed that nothing had received such tremendous abuse as their unfortunate rifle, both in the newspapers, in Parliament, and elsewhere. Under these circumstances they could do nothing but hold their own steadily, and not lose their heads, believing that if they had done the right thing, the issue would undoubtedly be successful. They should not be depressed or lose confidence because of the outcries set up in all directions when any new thing was brought forward. The case of the rifle was much in point. It had stood a great deal of adverse criticism, much of it by persons who were utterly incompetent to pronounce an opinion. A letter, for example, had appeared in the *Times* from a gentleman who said that he had met a very intelligent young soldier who had returned from India, who had stated that the general opinion was that the magazine-rifle was a bad weapon. That was published as a proof that the magazine-rifle was not worthy of the British soldier. They had to put up with criticisms of that kind, but if they kept on steadily remedying such little defects as might appear, they would in the end have a rifle like the magazine-rifle, of which they now heard absolutely no complaints, and an ammunition which was passed million by million without one single rejection. He had made these remarks upon a Paper which he thought had revealed in a very interesting manner the system upon which small arms were now made; and the specimens exhibited would show to the members the various stages through which the complicated mechanism had to pass.

Dr. Anderson.

Lieut.-Col. W. B. Hemans observed that, as a ballistic rifle, the Lee-Metford was in every way satisfactory, and he thought that would be freely endorsed by foreign opinion. But that was not the case with its magazine arrangement. Foreign opinion in regard to that supported two divergent systems. One was the latest French plan, originally embodied in the German rifle of 1888, the clip containing the cartridges being expended with the magazine. For fire-discipline, almost every country now agreed that that was the best system. The soldier would not manage his ammunition in a proper way, and, for fire-discipline, it was better that he should habitually use the rifle as a single-loader, and only use it with the magazine in by order. Many countries that had carefully considered the question, had stated that that was the best

Lieut.-Col. W. B. Hemans.

Lieut.-Col. W. B. Hemans.

system for a magazine rifle. With regard to the question of a fixed magazine in the rifle, the Lee-Metford was only one-half the latest development of the Continental system. In its entirety the fixed magazine was used in the rifle, with a loading-clip for cartridges. What was that but the little clip, in which they put the cartridges, as many as might be required, into the magazine? The fixed magazine might be right according to English ideas, but, according to Continental ideas, they had thrown away one-half of the system, the loading-clip, or lame. The question was one for experts to decide. Again, Continental opinion would emphatically condemn the breech-action of the Lee-Metford rifle, as too complicated, consisting of too many parts, with too many screws, and not fit to be placed into the hands of the soldier, who was unable to look after the action. Indeed, the musketry regulations strictly enjoined that he should not do so. If anything was wrong with it, the action must pass through the hands of the armourer. The general tendency on the Continent had been to get such an action as might be entrusted to the soldier himself, that he could put it to rights with his own hands, without the intervention of the regimental armourer at all. The latest development in France was the carbine on the Berthier system, with which the French cavalry was now being armed. The breech-action consisted of 8 small parts, 7 of which were simplicity itself, there being nothing that could go wrong. There was not a single screw among those parts. A soldier could easily strip the whole action by the exercise of a little dexterity, and put it right. The only thing that could possibly go wrong was the extractor. It was a very small elastic part that had to be made of the highest tempered steel. It had to perform the important function of extracting a fired cartridge and throwing it out with considerable force. The French soldier carried two spare extractors on his person; and, if anything went wrong on the field of battle, he had to withdraw the bolt and strip the whole action by a *tour de main*. Colonel Hemans, though not a skilled man, and knowing nothing of rifles, could, in less than a minute, strip the whole action, replace the faulty extractor, insert the bolt again, and resume firing. Next, as to the question of price, which was exceedingly important. He would take the trade price, which was the Government, or the private shop-price, plus whatever the customer could be induced to give. He would base his argument on the Government shop-price alone. From the last available returns of the Ordnance Factories, published in March last, it appeared that 97,127 rifles were made in 1890–91, at a cost of

£3 12*s.* 5*d.* each, equivalent to 90fr. 50c. Now the cost of the latest French rifle, the Berthier, manufactured at St.-Etienne, was 60fr. He had no statistics for other foreign rifles; the trade-prices were no guide at all. But he knew as a fact that the shop-price of every magazine-rifle in Europe was less than the French Government shop-price of 60fr. It followed that the Lee-Metford rifle was 50 per cent. dearer than any other magazine-rifle in Europe. That was a great calamity for this country. The trade in small arms had, in fact, been driven out of the country by the adoption of the expensive rifle which the British Government had fixed upon. Regarding the question from the tax-payers' point of view, what had been the history of small arms since the Crimean War? There had been three arms before the Lee-Metford rifle: the Enfield muzzle-loaders, from 1856 to 1866; the Snider rifle breech-loader, from 1866 to 1876; and the Martini-Henry, from 1876 to 1886. According to the doctrines of chance, the Lee-Metford had only three or four more years to live, and he would be a sanguine man who would prophesy even that. The belief that it would not have a long life was fully justified by Continental opinion, according to which another tremendous change in military small arms was imminent, its leading principle being that the army whose soldiers could carry the greatest number of rounds into action would win the day. With the Lee-Metford rifle, on the well-known principle that no soldier could carry more than $6\frac{1}{2}$ lbs. of ammunition into action, British soldiers could only have 100 rounds. By reducing the calibre from 0·315 inch to 0·2535 inch, they could carry into action 160 rounds. Thus 60 per cent. efficiency was conferred upon the soldiers who had small-calibre rifles. Of course there was a difference in the weight of the bullet, one being only 10 grams, whilst the other was 14 grams. How, then, was the army that used the lighter bullet to get the necessary enemy-repelling power? That question had already been solved by France. He had some returns of experiments made a few days ago with the $6\frac{1}{2}$-millimetre rifle, showing the solution of the question—by conferring an enormous increase of muzzle-velocity upon the bullet, amounting to 2,624 feet per second. Therefore the lighter bullet, over fighting ranges, had the same killing-power as the heavier one. The usual tests had been made by firing into the bodies of dead horses, and obtaining medical reports upon the wounds thus made. The experiments proved that the small-calibre rifle actually had 62 per cent. more efficiency than the Lee-Metford rifle. That was a deplorable thing for the

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tax-payer, because in a year or two there would perhaps be an entire change of rifle, which would cost between three and four millions sterling. From the trade point of view, he would reiterate the statement that the introduction of the Lee-Metford rifle had driven the trade in similar small arms out of the country. Its trade-price would be between £5 and £6, which no one would give. All countries used to come to England for the Martini-Henry rifle, the trade-price of which was £2 10*s*., and there was an enormous business done both in guns and ammunition. England had always been liberal and large-minded, allowing Government ammunition to be made in the trade. That was now all gone. Within the past few weeks, he knew of an order for 65,000 rifles that had been brought to England, but was taken away in three days, because no one would give £5 for an English rifle, when a first-rate foreign rifle could be bought for £3 5*s*.

Mr. Woods.

Mr. E. Woods, Past-President, said he had no claim or interest in the gun trade to justify his addressing the distinguished company of officers of the Small Arms and War Departments that was present. He concurred in everything that had been said by Dr. Anderson with regard to the Paper, which he believed would be of great value to the Institution as a record of the existing state of the small-arms manufacture, and of its early history. His only claim to speak on the subject was that he had been struck with a passage in the Paper on the English "gun-trade." He ventured to think that the Author had been a little hard upon the gun-makers of England in attributing to them a want of energy in initiating action and introducing modern machinery procured by them in the first instance from America. In the Paper, it was stated that "an immense demand of Enfield rifles for the United States during the Civil War, found them quite unprepared," and that "they utterly failed to meet it;" also that, "the loss of the military-rifle trade with foreign countries may be dated from that time." He thought that the Author was under some little misconception as to the early history of the trade, for, as a matter of fact, during the American War more than 1,000,000 rifles were supplied by Birmingham and London gun-makers. At the meeting of the British Association at Birmingham, in 1865, a Paper was read descriptive of the early gun-trade, by the Chairman of the Birmingham Small Arms Company, and from that Paper it would be found that Birmingham alone supplied 750,000, and London the remainder. The total number supplied to America during the Civil War, from

1861 to 1863, was 1,080,000. The Author had been a little severe on the manufacturers in the conclusions which he drew from his premises, but Mr. Woods thought that those premises required some correction. It was quite true that the manufacturers at Birmingham were at first somewhat slow in following the Enfield lead, but they were dependent upon their own private means for forming a company, establishing a very large manufactory, and equipping it with the modern machinery necessary to manufacture interchangeable guns. In addition to that, they had not at the time too much confidence in the chances of receiving Government support when their premises should have been rendered able to supply arms. With reference to the loss of the military-rifle trade, as a matter of fact very large supplies had been sent to France, Prussia, Russia and Turkey. The National Arms Company, of Birmingham, supplied 100,000 rifles to Prussia, and the Small Arms Company had sent 114,000 rifles to France in less than eight months. With reference to the trade leaving England, that might be accounted for by what Colonel Hemans had so eloquently described, rather than by the cause to which the Author had attributed it. He had made those remarks because he thought that those interested in the gun-trade might feel themselves a little discredited by the observations of the Author, founded, he believed, on a certain amount of misconception. After satisfying himself that the facts as stated were correctly recorded, the Author might possibly see his way to the conclusions drawn from the premises he had assumed. Mr. Woods.

Dr. Anderson asked Colonel Hemans why, if the British Government chose to adopt a costly rifle, British gun-makers should feel bound to manufacture that rifle only, instead of following the example of the French, Austrians, and Belgians, and producing a rifle of their own, which would be cheap as well as efficient, to offer to foreign nations. He also asked what the Berthier rifle would cost if made in England. It appeared from the Author's statement that wages abroad were about one-half of what they were in England, while the hours of labour were eleven as compared with nine. Of the £3 12*s.* 5*d.* mentioned by Colonel Hemans as the cost of the rifle, only 9*s.* or 10*s.* represented material, the rest representing labour, and including charges for depreciation of machinery at 10 per cent. per annum, for buildings at 5 per cent. per annum, and, in addition, a sum of money which would extinguish the special expenditure incurred in adapting existing machinery to the production of the new arms, and the purchase of new machinery, amounting in all to Dr. Anderson.

Dr. Anderson. about £96,000 in 6 years; so that, taking into account the low wages abroad, it would be found that the English rifle was made very nearly at the same price as the Berthier rifle on the Continent.

Col. Hemans. Colonel HEMANS replied that the French rifle to which he had alluded could be made in England at a Government shop-price of about 54*s.* per rifle. Of this sum, 9*s.* would be for material, and 45*s.* for labour and establishment charges. In France, the figures would be 48*s.* per rifle, of which 39*s.* would be for labour, &c. English labour was about 15 per cent. dearer than French labour, and applying that to the labour charge, the result stated was obtained. As regarded the reason why the English Government, having adopted any rifle they might approve of, should affect the manufacturer of another arm, who thought his own rifle a good and cheap one, the best answer to that question was to be found at p. 132 of the Paper, where it was pointed out what a great advantage it would be to a manufacturer if he could get a certificate of the excellence of his arm from a Government department. The best certificate he could get of the excellence of his arm would naturally be its adoption by the Government. Many customers would not stop to inquire into the merits of different military rifles; if they were Government arms, and cheap, they would buy; if not, they would go elsewhere.

By the President's permission, he exhibited a specimen of the Berthier rifle which had been made to take the Lee-Metford ammunition, with a view to obtain a trade for it in England. Its main principle was that it was invariably used as a single-loader, having only one cartridge, except when the section-commander ordered it to be used with the magazine in. The action was exceedingly simple. The soldier could carry it a long distance over his shoulder. There was a safety-arrangement—a little catch at the side which gripped the trigger—so that it was perfectly safe. When he wished to fire, he pressed it forward with his thumb. When the magazine was used in battle, it was expended with the ammunition; it was a little clip that only cost about a half-penny, and gave no trouble whatever. Of course, when not in battle, the clips could be recovered and used 100 or 1,000 times over. If the magazine had to be unloaded, there was a little ejector for the purpose in front of the trigger-guard. The soldier could take entire charge of the action. There were only eight parts in it, and not a single screw among them. When it was withdrawn (which could be done by turning a little screw) it was so strong and solid that it could be thrown against the wall or ceiling

without being injured. He would himself strip the action to show its extreme simplicity. Its fore-part consisted of three simple parts. It was the extractor only that required care, though not more than the extractor of the Lee-Metford rifle. In France it was recognised as being delicate, and spare extractors were provided. The movable head was the little part butting up against the cartridge and taking the longitudinal strain. The extractor-guard worked round, and carried the extractor with it. He held in his hand the rear-part of the action, and would show how easily it could be dismounted. The first process was un-cocking, which could be done by the hand. The parts were the main-spring, the striker, the cocking-piece, the main lever-piece, and the binding-nut, which latter was considered a triumph of ingenuity, because it abolished the need for screw in the mechanism. The whole thing was so simple that it was almost impossible for it to get out of order, with the exception of the extractor, of which about 3 in 100 rifles got out of order if 1,000 rounds were fired from each rifle. The parts could be easily put together again, as he would himself demonstrate. The rifle was fired at Bisley last summer, alongside the Lee-Metford rifle, at the same targets, and to all intents and purposes it made identical practice. The cost of the arm in the trade would be about £3 10*s*. With regard to the cost of the ammunition of the Lee-Metford rifle, which of course should be regarded as part of the rifle itself, foreign opinion was exceedingly favourable to the black-powder cartridge. It regarded the bullet as excellent, and the case as good, lending itself easily to extraction, and the black powder was also regarded as good, giving a muzzle-velocity of 1,850 feet per second with $4\frac{1}{2}$ grams of powder and a 14-gram bullet. He did not think that the black powder caused particular fouling, and it might therefore be considered pretty good. With regard to the smoke-less-powder cartridge, the bullet and the case were good; but he did not think that foreign opinion regarded the cordite powder highly. The question was a complicated one, and, without going a little into chemistry, it was almost impossible to say why foreign opinion should not be in its favour. He might cite the opinion of an eminent chemist—Dr. Hodgkinson. In his "Notes on Explosives," page 24:—

Col. Hemans.

"The solubility of gun-cotton in acetone is employed as a means of combining it mechanically with other substances, such as aniline, nitro-glycerine, camphor, nitro-derivatives of hydro-carbons, &c., with a view to regulate the rate of burning or explosion. A considerable number of such mixtures have been patented, and many others proposed. The mode in which the gun-cotton dries

Col. Hemans. up from the acetone solution is very convenient for this purpose. It retains liquid substances enclosed as in a jelly, and, according to their nature and quantity, the gun-cotton mixture may be hard and elastic or only just solid.

"Cordite is one of these mixtures containing gun-cotton, camphor, and nitroglycerine in certain proportions. Another convenience of the acetone solution of gun-cotton is that, before all the solvent has evaporated, the mixture may be pressed or cut into pieces of any required size, or even squeezed into the form of wire."

That gave a good definition of cordite; and it was most instructive when taken in connection with what was known of foreign smokeless powders, such as the French new white smokeless powder. The French were well satisfied with their smokeless powder; but, strangely enough, it was, bulk for bulk and weight for weight, about half the strength of English cordite, which the French considered too strong, the margin of safety being insufficient. Two grams of cordite gave a 14-gram bullet about 2,000 feet per second muzzle-velocity with 14 tons pressure per square inch in this rifle; but a slight increase in the charge would make it so violently explosive as to disable the gun. In France, such a small increase as half a gram or less would be regarded as a dangerous factor with smokeless powder. He did not know what the charge of the French B. N. would be for the gun he had referred to, but it might be expected to show a margin of safety of at least one gram.

Dr. Anderson. Dr. ANDERSON feared Colonel Hemans was giving baseless opinions only. In the first place, cordite did not contain camphor; and the statement about the destructive effects of an increase of charge was absolutely untrue. Cordite, like black powder, must be made of sizes to suit the special nature of guns, and must also be kept at approximately the most advantageous gravimetric density.

Col. Hemans. Colonel HEMANS said he had cited the statement of Dr. Hodgkinson, written in an official pamphlet by authority of the War Office. He might quote a comparison between smokeless powders and black powders, which readily lent itself to the illustration. In the 12-pounder field-gun, the service-velocity was about 1,710 feet per second, which corresponded with 240 foot-tons of work done; that was, the work done by 4 lbs. of black pebble powder (S. P.). With 1 lb. of the powder in 30 cubic inches space, 60 foot-tons of work was done. 2 lbs. of French B. N. powder would be required to do the same work. In other words, 1 lb. of French B. N. powder, working in 60 cubic inches, would give 120 foot-tons of work. He believed that 1 lb. of cordite would do the same amount of work as 2 lbs. of B. N., or 4 lbs. of S. P.; 1 lb. of

cordite working in 120 inches (the capacity of the powder-chamber of the 12-pounder field-gun) would give 240 foot-tons of work. Abroad, at any rate, cordite was considered too strong. For himself, he considered it a first-class powder, but it required to be slowed down a little. It possessed an enormous advantage in that it could be moulded and cast into any form, and might, later on, help towards doing away with the metallic cartridge-case in fixed ammunition. Col. Hemans.

Sir Benjamin Baker said the question of the manufacture of small arms appeared at first glance rather remote from the general interest of the Institution. What they had heard from Colonel Hemans read to many of them like a chapter out of the Proceedings of the Small Arms Committee; but it showed the extreme difficulty which that Committee must have experienced in deciding between the merits of the different rifles submitted, and they might have proceeded with the present discussion for another twelve-month, and found just as able and zealous advocates of a dozen other forms of rifles as Major Hemans had been of the French rifle. As Civil Engineers, few of them would be called upon to manufacture rifles; and he would therefore confine his remarks to such points as had a more or less direct bearing upon the pursuits followed by themselves. It was hardly possible to do justice to the subject of the manufacture of small arms in a Paper, however well it might be illustrated, and however fine the exhibits. The most popular part of every exhibition was the machinery in motion, and in order to understand the perfection of the advance to which this manufacture had attained, it was necessary to go through a small-arms factory and to see the ingenious milling and other machinery employed to shape the various parts of a rifle. It had not been possible to do more in the Paper than enumerate the different processes, but one point that was very interesting was the simple way in which the barrels were now manufactured. A piece of steel, about 16 inches long and $1\frac{3}{8}$ inch in diameter, went in at one pair of a train of rolls and came out in 30 seconds at the other end, as a barrel ready to be bored and turned. In the last century, Spanish barrels of course were in greatest repute, and the names of the leading Spanish makers were as well known as those of the violin-makers of Italy; but, as regards the number of heatings, the practice was exactly the converse. It would be impossible to say how many heatings a fashionable Spanish barrel then underwent, certainly a hundred; in fact, he could hardly understand how any virtue was left in the iron, or how it was better than a burnt-out furnace bar. For the most favoured Spanish Sir Benjamin Baker.

Sir Benjamin Baker.

barrels, they commenced with about 40 lbs. of iron, and this was wasted to 6½ lbs. by the time it was finished. As much as £40 was often given for a barrel by a first-rate maker. The records of the last century threw side-lights upon the way in which the best barrels were made in England; because they told how poor people on the great North road and other highways leading to London collected the nails that fell from the horse-shoes, and found a ready sale for them to the gun-smiths at 10*s.* per cwt., and it took about 28 lbs. to make a barrel. The way in which the gun-smiths proceeded, was to take the nails and place them end upwards in a little hoop of iron 6 inches in diameter and 1 inch wide, to bring the pile up to welding-heat, draw it out to a bar about ½ inch square, coil that round a mandril and weld, very much as Lord Armstrong did his big guns some years ago. There was no longitudinal strength of barrel, except that due to the edge-welding of the coil. The French, on the other hand, manufactured what they called a "riband" gun, in which they started with a lap-welded tube, to give longitudinal strength to the barrel, round which they coiled a band of iron about 1 inch wide, with chamfered edges, so as to overlap, for welding to each other and to the tube. The theory of the thing was very perfect even in those early days, for the fibre of the iron ran the right way in the lap-welded interior core for longitudinal strength, and the circumferential resistance was provided by the band. The reason he referred to the "riband" gun was, that it led up more than 100 years ago to the wire-construction, which at the present moment so much occupied the attention of the British Government and of the European Powers, and was now being introduced generally into the service. The subject was of such great general interest at the present time, that he would sketch as nearly as he could what he understood was the system of construction of the wire-bound gun-barrels made in France a century ago. He would draw it like a Parliamentary railway section on an exaggerated vertical scale, so as to show the principle better. The bore would be about ¾ inch —that of an ordinary musket-barrel, and the ordinary lap-welded tube would be turned, shaped down somewhat as shown in *Fig. 6.* A layer of wire was wound on about one-third the length of the barrel, soldered and finished off to a smooth surface; a second layer of wire was then wound over this and soldered, and finally a third layer of wire was carried the entire length of the barrel. In putting on the wire in order to wind it tight, it had necessarily an initial tension, and the iron tube was put into compression. There was no definite tension aimed at, as in modern wire-gun

construction, but it was unavoidable that the initial stresses in these early guns must have approximated to those theoretically desirable. As four or five Papers on wire-construction had been contributed to the Proceedings by Mr. Longridge during the last thirty-two years, it was very interesting to know what the French

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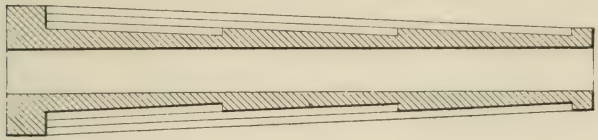
Fig. 6.



were doing last century. Lest it might be thought that he was drawing somewhat on his imagination, he would read a description of the mode of manufacture, as it appeared in an edition of the "Encyclopædia Britannica" published a hundred years ago. After speaking of the "riband" gun, the success of which led to the introduction of wired barrels, it said:—

"These were invented by an ingenious workman at Paris named Barrois, whose method was as follows: Upon a thin barrel, filed and dressed as usual, he rolled as close as possible, and in a spiral direction, a tempered-iron wire about the thickness of a crow-quill, the first layer covering only the re-inforced part. The turns of the wire were soldered to each other, and to the barrel, with a composition which he kept a secret. The wired part was then filed smooth and bright, but not so much as to weaken it; a second layer of wire was applied over the first, extending two-thirds of the length of the barrel, and this being smoothed and brightened like the first, a third layer was applied, which covered the two former and reached quite to the muzzle."

It was further stated that these barrels were very beautiful in appearance, because the solder and the iron-wire made a pretty combination when polished; but they cost £5 a barrel, and were therefore abandoned, when people were rather hard up for money, at the time of the French Revolution, in favour of the old lap-welded barrel. The use of wire had now, however, been vigorously resumed, and Mr. Longridge had done perhaps more than any other man in the country to direct attention to it. No one acknowledged that more than himself, although he disagreed with Mr. Longridge in many of his reasons for favouring wire, and had little confidence in his facts or conclusions. In 1860, in his first Paper, Mr. Longridge prophesied that if large guns were built up of hoops, the concussion of firing would soon shake them loose; and further, that the special requirement was that each

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layer of a gun should be under a definite calculated initial stress, which could be attained only by the use of wire. He said it was perfectly impossible, when constructing guns on the principle of shrinking one tube on to the other, to know what the stresses were, whereas in the wire-guns they had a certainty; the desideratum was to "construct a vessel in such an initial state of equilibrium that when the varying strain, caused by the internal pressure, should come upon it, the initial strain should be as it were complementary to the induced strain, and the sum of the two should be constant throughout. This might be nearly accomplished by wrapping successive layers of wire with proper tension round an internal core." This year, Mr. Longridge, referring to the service pattern of guns and the uncertainty as to the amount of initial stress on the various members, said, "As soon as the territory of the ascertainable is left and that of the unknown or indeterminate entered upon, a position of safety is left for one of chance, and this is a departure which cannot be too strongly condemned, when not only men's lives, but the safety and honour of the country, are also concerned." If that meant anything, it meant that the guns, as constructed for the last thirty years, were unsafe, and that, in some mysterious way, the honour of the country was involved, because the initial stresses could not be calculated with exactitude, and might on some fibres of a tube even exceed the elastic limit! A moment's glance would show that if there was one thing which could not be calculated, it was the distribution of the stress on the wire of a wired gun. It was simple enough, no doubt, if, with Mr. Longridge, one considered only the laying-on tension, and ignored the bending of the wire round the barrel and other complications. Even a child knew that in bending a thin wire round the finger, the elastic limit was exceeded, and the wire remained in a spiral form; and it was unjustifiable to ignore such stresses when claiming exactness of calculation in the case of wire-guns. But, more than that, they began with a material which was under heavy initial stress in consequence of the way in which it was manufactured. Lord Armstrong, ten years ago, whilst considering the question of wire-guns, stated that he was, when testing some wire, surprised to find that, though the breaking-strength was lowered very much by annealing, yet the elastic limit was raised from the 25 tons per square inch to about 35 tons per square inch. He did not at first see the reason, but afterwards found it was due to the heavy initial stresses left in the wire in the process of manufacture. It might, therefore, be taken that the diagrams of the stresses on wire-guns given by Mr. Longridge in successive

volumes of the Proceedings, did not represent the actual facts of the case. They represented an ideal material, viz., wire which had no initial stress from the process of manufacture nor from bending round a cylinder under high tension—a thing which did not exist in practice. When this was taken into consideration, there was no more uncertainty as to initial stresses in the case of the present service gun than there would necessarily be in the case of wire-guns; it was just as certain what the stresses were in the guns as now used in the service, as it would be with all the refinements of putting on the wire. They knew they must have occasional stresses up to the elastic limit in both instances; but what did that matter? They were equally at fault themselves on civil engineering matters, if it were a fault, which he did not admit. For instance, by the Board of Trade rules, they must not exceed a stress of 5 tons per square inch on any part of the iron of a railway bridge, yet they knew perfectly well that if the riveting was well done, there would be 12 tons per square inch upon the rivets, from contraction. It could be easily proved by experiment, as he had proved over and over again, that they had 12 tons per square inch on the rivets if the work was good, but nothing happened either from vibration or otherwise with the hundreds of millions of rivets which had been working for years under that condition. The Board of Trade perhaps did not know it. He proved it by jointing two flat bars with thick covers so as to get long rivets and good contraction on them. The holes made in the centre bar were $\frac{1}{4}$ inch larger than the rivets. On one side of the joint, instead of rivets, he put in three bolts, perhaps 6 or 8 inches long. They were screwed up until they were drawn out beyond the elastic limit, say, $\frac{1}{16}$ of an inch. The specimen was then put into the testing-machine and pulled to see which end went first. Of course the only thing that held it together was the elastic reaction of the bolts and the rivets. He had found in making this experiment sometimes it went on the bolted side, sometimes on the riveted side; but if the work was well done with hydraulic riveting there was never in any case 10 per cent. difference between the two. This proved to demonstration that the rivets had the same reaction on them as the bolts; and they knew by stretching the bolts $\frac{1}{16}$ inch by direct tension that the elastic limit was about 12 tons to the square inch. In some cases he had used bars dipped in linseed oil; in other cases, he put them in the fire, and oxidized the surface a little bit, when immediately the strength of the point became at least double, showing that the strength depended simply upon the elastic limit of the material and the

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coefficient of friction. He had also planed out rivets through the centre, and with a micrometer had seen that the rivet contracted when it was set free, an amount corresponding to the elastic limit of 12 tons per square inch in iron, and 16 tons in steel. No doubt in guns, whether made of hoops shrunk on over each other, or of wire wound on under a definite tension, they were liable to stresses beyond the elastic limit; but there was an enormous experience in civil engineering to re-assure the gunners that there was nothing to fear on that ground if good materials were used. He himself favoured wire construction, not because he had the smallest want of confidence in built-up guns now in the service, nor for the advantages claimed by Mr. Longridge as regards definite initial stress, but simply because steel in the form of wire was much stronger than a forging; and if a flaw existed it would affect a smaller section. As a Member of the Ordnance Committee, he knew that both built-up and wire-guns sometimes expanded and sometimes contracted under proof, as a result of the initial stresses re-adjusting themselves. Reverting to the question of small-arms manufacture, they all knew the extreme accuracy with which modern boring-appliances, as illustrated by the Author, did their work. In the last century, the barrels were bored by hand. A wooden frame was used, and the gun-barrel was drawn forward by a chain with a weight hanging over, and the man turned the winch-handle to bore the barrel. Some years ago, when examining, for the Government, the Menai Suspension Bridge, built by Telford some seventy years previously, he found in a cellar under an abutment, the old boring-machine which Telford used for boring the links. That also was a wooden bench, having on it a couple of winch-handles and cutters. The difference in refinement of the manufacture now was really most marvellous. With regard to ballistics, every one knew the state of affairs in the old times, when it was considered very good practice, at anything like 700 yards, even to hit anything the size of St. Paul's cathedral, firing from a rest. The variation right and left would be 100 yards, and the variation of range 200 yards one way or another. The Author had referred to another class of small arms which was indirectly of interest to engineers, as anything made of steel must be, viz., swords. Not long ago there was a scare about swords bending and breaking, and bayonets twisting, and *Punch* published a cartoon, in which a British soldier was shown trying to pin an Egyptian with a corkscrew on the end of his rifle, and an English officer trying to defend himself with half a sword. This was, of course, more or less a joke; but, for other reasons, the matter was referred by the War Office to Sir

Frederick Bramwell and himself to investigate. They found, on going into the thing thoroughly, what might have been expected, that as regards material, workmanship, and design, the swords supplied to the British cavalry were not excelled by those of any other nation in Europe. Samples of swords from different countries were submitted to them, and were tested in every possible way. What he said as to quality applied not only to the swords made by Mr. Rigby, but also to those made by Mr. Latham; the quality of material and workmanship was really as good as they could possibly desire. There were, nevertheless, some failures, and it was interesting to Civil Engineers to see what they were, because the cause and remedy applied to other things besides swords. The cavalry sword was a cut-and-thrust weapon, having fullered blade with a double edge for a portion of the length. One of the most severe tests was to depress it till it was bent about 9 inches. Their first work was to see what a depression of 9 inches meant as regards stress. On calculating for different portions of the blade what was the stress resulting from the bending, it was found that at the critical part of the blades, it was 96 tons per square inch. In that room they knew what 96 tons per square inch was, and as it was an alternating stress, every one knew, that without anything further, the sword must give. They ascertained further, that 96 tons to the square inch was two-thirds of the stress which would seriously bend, or absolutely break the blade. An alternating stress of two-thirds of the breaking strain meant very few alternations in any material. He had previously found, in trying chiselled steel and drift-steel at the Forth Bridge, that with one-half instead of two-thirds of the stress required to bend or break, they could only make about 400 or 500 alternations, with two-thirds only 20 or 50; and that a stress even only one-sixth of that which would seriously bend or break, would cause fracture in 500,000 bends on the average. It was clear, of course, at once, that this trouble from the bending and breaking of swords simply arose from over-anxiety in giving too severe a test. The quality, the pattern, and workmanship were admirable throughout, and the same failures would occur universally if things were tested to that extreme degree. The remedy was obvious. A tempered blade must be bent once at any rate, and examined to see that it came straight afterwards; but they need not go on bending it. There was no harm if it was always bent in the same direction. A specimen which would break in 50 bends, if bent backwards and forwards, would stand 15,000 bends in one direction, because, by putting on a stress beyond the limit of elasticity in tension, the

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limit of elasticity of compression was lowered, and *vice versâ*; and to go on backwards and forwards was absolutely to take all life out of the thing. There had been no trouble since the system of testing swords had been modified. Both Sir Frederick Bramwell and he were very much indebted to Mr. Latham for the perfectly frank way in which every process of his private manufacture was shown, and they were satisfied to find that a form of blade had been arrived at so proportioned to the stress at each point that they could not improve upon it in any way, either by theoretical investigation or by experiment. The form of blade had been arrived at tentatively, and they had nothing to suggest either as regards material, form, or process of tempering, beyond merely to ask the inspectors not to be so curious as to whether the blade continued in good condition. If they were to take some wire and wriggle it backwards and forwards half-a-dozen times to see if it was good, and then put it on a champagne bottle, and subsequently take it off every year and give it another bend to see if it continued good, it was only a question of time when the thing would come to grief. His Royal Highness The Duke of Cambridge had been kind enough to send for testing a piece of the celebrated Toledo sword-steel. That was tested mechanically for tension and bending, and also chemically, and was not found superior in any respect to the steel used for British private troopers' swords. Chemically it was, indeed, inferior, and, as a cutting weapon, he should be very sorry to shave himself with a razor made of it. It not only had lower carbon, but it had $\frac{1}{4}$ per cent. of copper. It was not intended to have the copper; that was an impurity which got in. Altogether, the superiority of Toledo steel was a myth.

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Major-General Arbuthnot found the Paper one of great interest, as he had been himself at the Small Arms Factory at Enfield seven years. With reference to the Author's allusion to the large additions made to the machinery and buildings in the years immediately preceding 1887; as General Arbuthnot was in a great measure responsible for those additions, it afforded him satisfaction to learn that the work he had initiated had been brought to such a successful issue by the Author. With regard to the barrel at Enfield, it might surprise many people to learn that, up to the year 1884, there was no specification whatever for the steel used. They obtained the steel in those days from one or two makers, and were perfectly satisfied with its quality. It never varied. It produced very good barrels; and that was, he presumed, the reason why it was not necessary to have a specification. After-

wards, competition became more keen, prices went down, and, instead of obtaining steel for the barrels, they had a metal which was little better than iron. It then became necessary to introduce the specification, so that the metal of which the barrels were made should be able to stand the stress it was likely to meet with in service. He believed that that specification, with slight modifications, was still in use, as it was originally drawn up in 1884 and 1885. With reference to the drilling of the barrel, there was no drawing of the drilling-machine in the Paper; but reference had been made to drilling-machines supplied by Messrs. Greenwood and Batley. He might mention the way in which those machines were introduced to Enfield. Mr. Arthur Greenwood one day brought to his notice the drilling-machines which were being used by the Italian Government, and mentioned how many barrels they could drill, and what labour was required; and the account appeared so favourable, that he obtained permission of the War Office to order two of those machines, which fully realised all that Mr. Greenwood had said about them. The following year they had six machines; and before he left Enfield there were, he believed, sufficient drilling-machines of that pattern to drill 3,000 barrels per week. He was afraid to state the saving effected by their introduction, because it was so large; but he was certain that it amounted to at least 8*d.* per barrel in labour alone, and that, for 3,000 barrels per week, represented more than £4,000 a year. With reference to the rifling of the barrel, Sir Henry Halford had found fault with the Author's statement that the rifle was satisfactory, instead of saying very satisfactory. He thought that the Author had exercised a wise discretion in not praising too highly any system of rifling, because, if a system of rifling was very effective for bores of 0·45 inch or 0·43 inch, with a muzzle-velocity of about 1,300 feet per second, it did not necessarily follow that the same system was equally effective for a small bore of 0·303 inch, with a quick twist of 1 in 10, and a muzzle-velocity varying from 1,800 feet to 2,000 feet per second. He thought it required a certain amount of experience, before any one could say which was the best system of rifling under those conditions. He believed that the Metford system was good, and he had no doubt that it would turn out satisfactory, and stand all the wear and tear and stress to which it was likely to be subjected. In small bores, the rifling was subjected to a different kind of wear from that in larger bores with lead bullets. It was well understood that with a small bore like the 0·303 inch, a long soft lead bullet could not be used; it would not take the rifling;

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it would strip. That was why it was necessary to have hard, nickel-coated bullets for small-bore rifles. The lead bullet was the same diameter, or a less diameter, than the bore of the barrel. In the case of the Snider rifle the diameter of the bullet was 0·577 inch; in the Martini-Henry, the bore was 0·45 inch, and the bullet also was 0·45 inch. Those two bullets were set up into the rifling. The clay plug in the base of the Snider bullet forced the lead into the grooves. The Martini bullet had no plug, but was set up in the rifle simply by the force or concussion of the charge of powder behind it. But in the case of the 0·303-inch rifle, the bullet, instead of being 0·303 inch, was 0·312 inch; he believed the mean was 0·311 inch. The bore of the rifle was 0·303 inch, and the depth of the groove 0·004 inch; so that, really, each bullet was the diameter of the bore plus the diameter of the grooves on each side; 0·008 inch added to 0·303 inch would give the diameter of the bullet. That bullet did not set up; it was forced through the rifling, and had to cut its way through by filling up the grooves. Therefore, the friction caused by the bullet must be great compared with that of the soft lead bullet set up into the groove by the powder. Until they saw what the effect of that would be with cordite powder, after the experience of some years, he did not think it was safe to say that one system of rifling was absolutely superior to another system. It was found at Woolwich, by experience, or at least, by constant use, that the muzzle-velocity fell off 10 feet per second, every 1,000 rounds fired from the rifle. That gave some idea of the amount of wear by the friction of the bullet passing through the barrel. As the infantry soldier fired roughly 200 rounds per annum, it would be five years before the velocity of the bullet fell off 10 feet per second, provided the rifle were properly treated. With reference to the cleaning of the rifle, they all knew what strict regulations were laid down for that purpose; but he did not know whether those regulations had been strictly adhered to. If any sand or grit, or foreign substance, were introduced to clean the barrel, the wear and tear would no doubt be much greater in a small bore than in the old large bore of the 0·45 rifle. As to the magazine and bullet, Colonel Hemans had stated that foreign nations did not like them. He really did not think it signified much what foreigners thought of the English magazine. He believed that it was in a convenient place, that it was easily loaded, and was in every way efficient. With regard to the bolts, he had not a word to say against the bolt of the Berthier rifle. He believed

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that it was perfectly good and simple, but he differed entirely from Colonel Hemans in regard to one advantage that he claimed for it, namely, that the soldier had it completely under his own control. That was a great mistake. He did not think that a soldier ought to have his rifle completely under his own control. He was sure to lose some of the parts, and was very likely to leave out the extractor, as Colonel Hemans himself had done in the course of his demonstration. If he, educated and intelligent, in putting the parts together, calmly left out the extractor, what could be expected of a soldier who did not care much whether he had an extractor or not? He believed that the question came before the Small Arms Committee whether bolts should be so simple or not, and it was determined, advisedly, that they should be so made that the soldier should not be able to take them to pieces too easily. In the Soudan, the sand covered a thing up in five minutes, and, if there were any more wars like that in the African desert, it was certain that, if a soldier could take the bolt to pieces to clean the parts, he would lose half of them before the day was over. The soldier could clean his rifle easily, and if anything went wrong with it, he had the sergeant or the armourer-sergeant to fall back upon. As to the rifle itself, he believed it was a thoroughly good and efficient weapon. Whether it was the best or not was another thing. Perfection had never been attained, but when the rifle was determined upon, he believed it was the best before the Committee. Many improvements had been introduced since the adoption of the English Lee-Metford rifle; but at the time it was adopted, he believed that there was no rifle that could beat it, nor did he indeed think that there was any rifle that would beat it now. He did not state that without some knowledge and experience. With reference to swords, a drawing had been exhibited of a muffle in which the swords were now held for hardening. Previously to the adoption of the muffle, sword-bayonets and swords were heated either in an open hearth or in molten lead. Both of those systems were objectionable, because, unless the lead were perfectly pure, the sword or bayonet-blade would be apt to take up impurities from the substance in which it was heated—chiefly sulphur; and, when a blade once took up sulphur, it became short, and was very apt to break in hardening. To obviate that, the muffle was designed by the manager of the Small Arms Factory. A model of it was shown at the Inventions Exhibition, and received honourable mention from the jury. The rolling of the sword-blade was done in one or two heats. The idea was obtained from Mr. Kirsch-

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baum, Solingen, the first place where he had ever seen swords made in large quantities by machinery. The introduction of the present pattern of sword was rather instructive. It was in the year 1885, when the Committee appointed by the Secretary of State to investigate the question of swords, reported in favour of the pattern now in use. At that time, the stock of swords was very small, and the whole of the cavalry having to be re-armed with the new pattern of swords, it became a serious question where they could be obtained. He had been extremely desirous, if possible, that those swords should be made in England, and he put himself in communication with some of the Sheffield firms, but was informed that the sword trade died out in Sheffield at the beginning of the century and had never revived; and there was not a single firm in the town willing to undertake the manufacture of cavalry swords. He then turned to Mr. Latham and Mr. Mole, but neither was then in a position to make swords in any quantity. Under those circumstances they were forced to go abroad. There was a great deal of talk at that time, as there had been since, about going abroad to get a supply of swords for the cavalry; but the Secretary of State went abroad simply because he could not get the work done in this country. Swords were made at Enfield, but they had never been made there before. Mr. Mole frightened him by saying, "For goodness' sake don't take it up, you will never do it," but he thought that what could be done elsewhere might be done at home, and accordingly they took it up, and the sword which was made at Enfield became the sealed pattern at the War Office. That showed they were just as capable of doing it as anybody else; and, if only a little energy and enterprise were shown, there was no reason why every sword in the hands of the cavalry should not be made in this country instead of abroad. With reference to the question of the loss of trade, he thought that the Author was right in stating that the small-arms trade had left this country, but he did not think that any other trade had left it. The only reason, he thought, why it had gone, was, that the demand of this country was not sufficient to keep a factory employed. As to other warlike material, Lord Armstrong's company would not say that the gun-trade had left the country; powder-makers and ammunition-makers would not admit that the trade had left the country, and would not despair of getting foreign orders; indeed, he might say that they had foreign orders at the present moment. But if there was a disinclination for embarking in large works for turning out war material, he did

not think it was so because the patent laws were at fault, but rather because of the system of Government contracts. It was well known that all contracts were so made as to terminate at the end of the financial year—March 31st. There was nothing more difficult and depressing to a manufacturer, than being obliged to work up to the fullest power to the 31st of March, and to feel that he would then receive no more orders for three or four months. When he was himself a Government official, he had fought against that system, and had not changed his mind because he was no longer an official; because he thought that running contracts should be made, not necessarily terminating at the end of the financial year. Under such a system things would be done cheaper and better, and no one would suffer except the Treasury in regard to the winding up of their accounts at the end of the year. It was a hard thing to finish a contract by the 31st March, and end by delivering 500,000 rounds per week, and then lie idle for three or four months, so that all the skilled hands had to be discharged, and afterwards taken back when a fresh order was obtained. He would appeal to Dr. Anderson to get the system altered, and give them running contracts. At the close of the Paper, the Author had alluded to machine-guns, but remarked that it was already too long for him to enter into that subject; he hoped, however, that the Author would find time to write another Paper dealing with machine-guns. Maj.-Gen. Arbuthnot.

Captain J. H. Thomson, R.A., asked permission to say a few words with regard to the curves in *Fig. 5*, which he did not think very reliable. He claimed some right to criticise them because he had himself determined them. The pressure-curve for cordite was arrived at by experiments with a very early variety of that explosive. The maximum pressure then obtained was about 5 tons per square inch higher than the present pressure, and they were aiming at a higher velocity than 2,000 feet per second. The maximum pressure certainly agreed closely with the pressures obtained with crusher-gauges, but, inasmuch as those curves represented effective pressures, and took no account of friction (which was considerable) they should not have agreed. In reply to Dr. Anderson no account was taken of the extra acceleration of the bullet after leaving the muzzle, due to the rush of gas following it. Not because it was unimportant; for it was no doubt considerable. To deny that would be to assert that a quantity of gas at high pressure, when suddenly liberated, would expand until it attained the pressure of the atmosphere in an infinitely short period of time. Moreover, he had had visible proof of the power Captain J. H. Thomson.

Captain J. H. Thomson.

of the gas in leaving the muzzle. In some experiments with very short barrels, the pressure was sufficient to strip the envelope from rear to front, turning the bullet inside out. But, when the experiments were made, there was no method available for arriving at even an approximation to that acceleration. The result of leaving it out would be to raise the calculated pressure above what it should be, especially in the first part of the bore. That would bring the effective maximum pressure considerably higher than it should be, neutralizing the effect of leaving the friction out of account. The method of arriving at the pressures by calculating from the velocity-curve was, he now thought, not a reliable one. There was a fine field for "fudging," or (to use its scientific name) "differencing." He owed it to himself to say that he honestly tried to avoid it, though it was always liable to occur; otherwise he would have smoothed out the curious humps which appeared near the maximum pressure. They occurred almost at the same place in both curves, and were doubtless due to some abnormal result or to some error of observation. But suppose a wave of compression were to start at the base of the bullet at the time of maximum pressure, and travel to the end of the cartridge-case, catching the bullet up again at the points where the humps appeared, the velocity of that wave, for cordite, would be approximately 3,700 feet per second, and with black powder, 2,900 feet per second; and the corresponding temperatures in air would be 5,400° F. and 3,200° F. respectively. Allowing for the difference in density of powder-gas, and for the effect, in the case of black powder, of the solid residue, those temperatures were not far from the actual temperatures of the gases. That might be called an excuse for the humps, though he did not attach much weight to it. The question had been raised as to whether the forward part of the barrel was sufficiently strong for cordite. It was known that the chamber was safe enough, because the pressure in it had been reduced below that due to black powder; but, inasmuch as higher energy was obtained with cordite, it was natural to suppose that the pressure somewhere in the bore was greater; and it was a question whether the pressure was too great at some point beyond the chamber. He thought that the curves were sufficiently accurate to show that there was a large margin of safety. There was a curve showing a pressure that would subject the surface of the bore to a tension of 20 tons per square inch; and the maxima of the two pressure-curves were above that. With the low steel in use, the elastic limit was very little more than 20 tons per square inch, so

that, with those high pressures, permanent enlargement of the chamber might be expected. No such enlargement had, however, been observed; and the conclusion was that the formula used for calculating the strength of tubes did not apply to rifle-barrels of small calibre, or that the elastic limit rose when stress was applied for a very short period of time. Captain J. H. Thomson.

Captain NATHAN, R.A., thought it was perhaps hardly within the scope of a discussion on a Paper upon the manufacture of small arms, to refer to the advantages and disadvantages of any particular system; but as Colonel Hemans had told the meeting what he conceived was the foreign opinion with respect to certain details of the service Lee-Metford rifle, he would ask permission to occupy a few minutes in dealing briefly with his remarks on the ballistic properties, the magazine system, and the bolt mechanism, of the present English rifle, in comparison with similar details of foreign arms. It had been stated by Colonel Hemans that the English bullet, weighing 215 grains, had a muzzle-velocity of 2,000 feet per second, and that the pressure developed in the chamber was about 14 tons per square inch. Comparing them with those of the most important foreign rifles, he might cite the following figures:— Capt. Nathan.

—	Calibre.		Weight of Bullet.	Muzzle-Velocity.	Pressure.
	Millimetres.	Inch.	Grains.	Feet per Second.	Tons per Sq. Inch.
Austria—Mannlicher, 1888-90	8·0	(0·3149)	231·5	2,073	..
Belgian—Mauser, 1889	7·65	(0·3012)	219·0	2,000	19·7
Denmark—Krag-Jörgensen, 1889	8·0	(0·3149)	238·0	1,968	15·1
England—Lee-Metford	7·7	(0·303)	215·0	2,000	14
France—Lebel, 1886	8·0	(0·3149)	231·5	2,073	..
„ Berthier	7·65	(0·3012)	205·0	2,073	14
Germany, 1888 pattern	7·9	(0·311)	225·0	2,034	21
Russia, 1891 pattern	7·62	(0·3)	214·0	2,000	..
Switzerland—Schmidt-Rubin, 1889	7·5	(0·2952)	211·5	1,968	15·1

He would, however, direct special attention to one point revealed by the figures quoted, viz., that the English rifle, firing cordite, differed in one important particular from other rifles that fired smokeless powder; that was, in the pressure developed by the explosion of the charge. This had been given by Colonel Hemans for the Lee-Metford rifle, as about 14 tons per square inch, a figure which exceeded that now obtained by about 2 tons, and was very much less than that developed by some of the foreign explosives. The low chamber-pressure was of enormous ad-

Capt. Nathan. vantage from a soldier's point of view, because it very greatly facilitated the working of the bolt, and completely did away with any difficulty in extraction. The whole of the present year's musketry course at Aldershot, and that of the troops of the Home District, as well as that of some other regiments, which meant an expenditure of about 3,000,000 rounds, was carried out with cordite; and there was not reported a single instance of a failure in extraction. Any one who had fired the rifle with the old black powder, which gave a pressure of 17 tons or 18 tons per square inch, and with cordite, would confirm his statement.

Whilst on the subject of ballistics, he wished to refer for a moment to the question of a further reduction in calibre, mentioned by Colonel Hemans. It had been universally recognized that the introduction of magazine-rifles would entail a largely increased expenditure of ammunition; but as there was a limit to the weight which a soldier could carry, reduction in calibre, and consequently in the weight of the bullet and cartridge, had always been the subject of experiment. A decrease in the weight of the bullet had the further advantages of an increase in muzzle-velocity, and therefore of a flatter trajectory, and of greater penetration. With the general introduction of military breech-loading rifles, calibres between 10 millimetres (0·394 inch) and 11 millimetres (0·433 inch) were inaugurated. The Swiss ballisticians who took the lead in that reduction of calibre, again led the way to a still further decrease. As early as 1879, Major Rubin, Director of the Swiss Laboratory at Thun, carried out trials with rifles, some of which had as small a calibre as 8 millimetres (0·3149 inch). In 1882, Professor Hebler, of Zurich, arrived at a calibre of 7·5 millimetres (0·2952 inch). Until recently, the smallest calibre military rifle was the 7·5 millimetre, Swiss Schmidt-Rubin of 1889. In 1891 Mr. Mannlicher, the engineer of the Small Arms Factory of Steyr, in Austria, still further decreased the calibre, constructing a magazine-rifle on his well-known system, having a calibre of 6·5 millimetres (0·2569 inch). Very exhaustive and complete experiments were carried out early in 1891 with this rifle, by the Technical and Administrative Committee at Vienna; a full detail of which, compiled from the official reports, made in July 1891 would be found in the July 1892 number of the "Revue d'Artillerie." Experiments had been recently made in France, with a rifle, also of 6·5 millimetres calibre, a notice of which appeared in the "France Militaire," of the 31st May, 1892. The practicability of such a small calibre as 6·5 millimetres, which was fully demonstrated by Mr. Mannlicher, appeared

therefore to have been first proved in Austria, and not in France. Capt. Nathan.
In the "Schweizerische Zeitschrift für Artillerie und Genie," March 1892, Professor Hebler, in his treatise entitled, "Shall we stop at a calibre of 7·5 millimetres, or diminish it still further, and if so, how far?" assumed that technical difficulties of construction no longer prevented the introduction of a still smaller calibre; and advised, on the strength of his own experiments, a calibre of 5 millimetres (0·1968 inch). One valid objection was, however, recognized by him, and that was, that the maximum pressure was too high; he reckoned it at 29·5 tons per square inch, and thought that it would cause a setting-up of the locking lugs of the bolt; but added, that the safety of the bolt was sufficiently insured by the invention of the Vienna gun-maker Mr. Karl Krnka, in which the bolt had four, instead of two locking lugs. That might be the case, but Captain Nathan thought that very exhaustive experiments would have to be made, to prove, apart from the safety of the bolt, whether the cartridge cases would stand, and whether extraction and easy manipulation of the bolt mechanism would be possible, with such extremely high pressures. With regard to the effects of these small calibre bullets in warfare, he gathered that Colonel Hemans considered the striking energy of a bullet to be a measure of its stopping-power; and that the decrease in weight due to the decrease of diameter was compensated by the increase in velocity. The real measure of the stopping-power of a bullet, or the shock it produced, would, however, appear to be rather the amount of the energy expended in its passage through the body. The reduction in calibre had necessitated the introduction of a much harder bullet, a lead core in a jacket of steel or copper-nickel alloy; which, instead of setting up on impact as did the old lead bullet, and by so doing expending in the body a large amount of its energy, passed through with little, if any, deformation, and came out with a comparatively small loss of energy. The nature of the wounds produced by such a bullet, had been the subject of experiments in this and other countries, bodies of dead horses, donkeys, &c., being used for the purpose. The matter was discussed by many eminent surgeons at the Surgical Congress held in Berlin in July last, and much had been written about it. A great deal of course depended on the construction and material of the bullet, the striking-range, and the portion of the body hit. Much difference of opinion appeared to exist among the experts, but the general view seemed to be, that flesh wounds would not be dangerous, and would be easy to heal; but that if the bullet met with much resistance,

Capt. Nathan. such as that offered by large bones, its shattering effect would be very great, especially at short and long ranges.

With regard to magazine-systems, the object aimed at by the authorities in this country, was to obtain a rifle to be used ordinarily as a single-loader, but containing, in a suitable magazine, a reserve of cartridges, available for instant use on the order for magazine fire being given; but which should be, until such time, so shut off, that the cartridges could not be expended by the soldier without the knowledge of his section-officer. How those requirements were met in the Lee-Metford rifle would be best understood by an inspection of the samples of the service-arms exhibited. The magazine was loaded by the insertion, from above, of single cartridges, and it could at any moment be refilled entirely, or after the expenditure of any given number of rounds, as opportunities for so doing offered themselves. The cartridges were made up in paper wrappers, in bundles of ten, and formed a compact parcel, occupying a minimum of space in the soldier's pouch and in the small-arm ammunition-boxes—a most important point from a transport point of view, in these days, when, owing to the introduction of the magazine-system, an expenditure of ammunition much larger than formerly must take place. Turning to a consideration of the foreign systems, they might be divided into three groups, neglecting the old and practically obsolete system in which the cartridges were carried in a tube under the barrel, as in the French Lebel, which held 8, the Norwegian rifle, also holding 8, and the Portuguese Kropatschek, which held 9. In the first system, the magazine was filled by pressing cartridges into it from a charger which held 5, the charger itself not entering the magazine, but being thrown clear by the advancing bolt, or removed by the hand. The Belgian Mauser, pattern of 1889, the recently adopted Turkish rifle of almost identical construction, and the Russian rifle, pattern 1891, were examples of that system. Those rifles could not be used as single-loaders so long as there were any cartridges in the magazine; that is to say, if a soldier put a single cartridge into the chamber and then attempted to close his bolt, he would force a cartridge out of the magazine on to the one in the chamber, and jam his rifle. They could of course be used as single-loaders if the magazine was empty; but, as stated by Colonel Hemans, that was not intended, it being an essential feature of the system, for the sake of the fire discipline, to teach the soldier only one method of loading. As in the Lee-Metford rifle, a partially-emptied magazine could be refilled at any time, by the insertion of single cartridges.

The Swiss Schmidt-Rubin, pattern 1889, containing 12, the Danish Krag-Jörgensen, pattern 1889, containing 5, and the Spanish Mauser, pattern 1890, also containing 5 cartridges, in the magazine, although filled by means of chargers, resembled in principle the English arm. All three could be used as single-loaders when the magazine was full, and the magazine itself could be replenished at any time by loading in single cartridges, which were issued for the Swiss and Danish rifles in bundles as well as in chargers. In the Swiss and Spanish rifles the cartridges were kept in reserve by lowering the filled magazine slightly, so that the bolt in advancing, passed over, instead of catching and pushing forward the top cartridge into the chamber. In the Lee-Metford rifle, the cut-off, which was pushed in over the top cartridge, kept it down, and also served as a platform for single loading. The Danish rifle had a cut-off, the principle of which was the same as that of the Lee-Metford. He might mention that the Board on Magazine Arms which assembled in New York in November, 1890, "to consider and recommend a suitable magazine-system for rifles and carbines for military service," after having tried 53 guns, including the service-arms of Austria, Belgium, Denmark, England, France (Berthier), Germany, Japan, Portugal, Roumania, Russia, and Switzerland, "unanimously arrived at the conclusion that an arm showing itself to be an efficient single-loader, a rapid magazine-arm, holding meanwhile that magazine in reserve, with a cut-off plainly indicating to the officers which class of fire is being delivered . . . . was the most 'suitable' for our military service, of all examined." "Such a system is found in the Krag-Jörgensen guns as improved and ultimately submitted to the Board." The Report was dated 19th August, 1892, and the Secretary of War has approved the selection of the Krag-Jörgensen system for trial, with a view to its adoption in the military service of the United States as recommended by the Board. Capt. Nathan.

In the third system, the 5 cartridges were contained in a metal clip in which they were inserted bodily into the magazine. The examples of this system were the Austrian Mannlicher, pattern 1888, the German rifle, pattern 1888, the new 6·5 millimetre Mannlicher rifle in course of adoption by Italy, the Netherlands and Roumania, and the French Berthier rifle and carbine, the former holding 4 and the latter 3 cartridges. Those rifles could not be used as single-loaders so long as there were cartridges in the magazine, nor could the magazine be replenished until the clip was emptied, and had dropped out through the hole cut for

Capt. Nathan. the purpose in the bottom of the magazine, or without removing bodily a partially emptied clip. Although the rifles of this group could be used as single-loaders when the magazine was empty, yet the ammunition for them was all issued in the clips; and he could not trace, in the German official regulations at all events, any instructions for the habitual use of single cartridges; on the contrary, it was expressly laid down that single loading was to be resorted to, only under exceptional circumstances. It would no doubt have been noticed that Great Britain was the only nation which did not use a charger or clip. It should, however, be remembered, that the English magazine held ten cartridges (eight in the Mark I), and that magazine-fire was the exception and not the rule—to be resorted to only for the last stage of the attack or sudden emergencies. Other considerations, which it would take too much time for him to enter into, led the authorities to decide against the clip or charger; he would, however, mention an all-important one, viz., the enormous loss of stowage entailed by that system of packing, and the extra weight of the arrangements. He had endeavoured to draw attention to the essential features of the magazine-systems in general use. Which was the best system was a question that could not be settled until the test of active service had been applied.

He would turn, in conclusion, to the bolt-mechanism of the Lee-Metford rifle, which was so vigorously attacked by Colonel Hemans, who stated that the aim of foreign military rifle-makers was to elaborate (a word that appeared to have been used advisedly) a bolt-mechanism which could be readily taken to pieces by the soldier; and drew a vivid picture of a French soldier armed with the Berthier rifle, stripping his bolt in the face of the enemy to replace a broken extractor, an operation which would take him less than a minute to perform, and which was accomplished by a *tour-de-main*. Surely he was not in earnest in suggesting such a proceeding during the heat and excitement of an engagement; it would partake much more of the nature of a *tour-de-force* than of a *tour-de-main*, to carry out successfully. The French Berthier bolt was, he explained, simplicity itself, consisting of only 8 parts, without any screws, the only component in it liable to go wrong being the extractor, "a very elastic small part that had to be made of the highest tempered steel." The strength of a chain was that of its weakest link, and it must be regarded as an admission of failure of the bolt-mechanism, when they were told that the extractor was so delicate and liable to give way, that every soldier was provided with two spare ones, and that he was instructed

and was even expected, to replace a damaged one on the field of battle. The Lee-Metford bolt, although it might to foreign ideas appear complicated, and although it could only be taken to pieces by the armourer-sergeant (a result which, by-the-bye, the authorities had purposely been at some pains to arrive at), contained an extractor which was rarely, if ever, found to fail, and which as a whole had stood long and severe trials in many thousands of rifles in the hands of the troops, in a way which had given complete satisfaction to everybody. The bolts, if carefully examined, would compare most favourably with those of foreign rifles, alike as to strength, number of parts, and simplicity of construction. Comparing the number of its components with those of some of the foreign rifles he had already referred to, it would be found that the bolt of the Capt. Nathan.

Austrian rifle consisted of	8	parts.		
Belgian ,, ,,	10	,,	, including 4 belonging to the locking-bolt.	
Danish ,, ,,	10	,,	, including one screw.	
French (Berthier) rifle consisted of	8	parts.		
German rifle consisted of	10	parts, including ejector and 2 belonging to the locking-bolt.		
Russian ,, ,,	8	,,	, including 2 screws.	
Swiss ,, ,,	9	,,		

whilst the Lee-Metford bolt consisted of 10 parts, including two screws and a bolt-cover, which was peculiar to the rifle, and was necessitated by the varying conditions under which it had to be used. What he had said of the bolt applied equally to the other components of the British Lee-Metford rifle. It was easy to make and simple to manipulate, and now that its details were perfected, and the small defects, incidental to the introduction of an entirely new pattern, had been, as pointed out by Dr. Anderson, completely remedied, it was and had proved itself in every way to be an admirable weapon with which to arm the troops.

Mr. E. A. Cowper said that the Author should be thanked for speaking out as to the causes at work tending to divert some of the standard trades of this country into other channels. Many years ago Mr. Cowper had done all he could to get the Birmingham gun-makers to adopt the machinery then being used in the United States, and had said that the Government would be sure to adopt it, as the gun-makers would not make the component parts of guns interchangeable. It was even argued by some makers that the barrels should not all be turned on the outside to one size as it would be expensive, and would waste the metal, but that Mr. Cowper.

Mr. Cowper. each stock should be carved out to suit its barrel. It was one of the greatest reproaches to English manufacturers, that they were not sufficiently enterprising to take up a new thing and give it a fair trial as foreign engineers, particularly Americans, did; and the Author was quite justified in saying that England "had permitted the initiative to be taken by others." The gun-trade being almost entirely confined to Birmingham, the insufficient number of skilled workmen placed the masters too much in the hands of their men, who would even borrow £5 or £10 when they knew their master had just got a large contract, and would, of course, go away for a week or a fortnight. At last the gun-makers, finding their trade departing, and Enfield making most of the guns wanted at home, combined and built a factory and made money. It was a pity that other manufacturers did not take a lesson from that, and do it in time. The cold-straightening-machine described by the Author was, he thought, an excellent tool, and no doubt enabled the workman to straighten barrels quicker and better than by hand. The eye was the best gauge of the barrel being really straight, and it was wonderful what a slight error could be detected. The method was to look through the barrel towards the light, having half the bore in light and the other half stopped by a dark screen; the lines of light through the barrel then showed the slightest defect from straightness, *Fig. 7*. He agreed with the Author as to the advantage to workmen of a "side-light;" and thought it a pity that many fitting-shops were dependent on "top" or sky-lights alone. The Author had spoken of the Enfield bullet and of some others, but had not mentioned one bullet intended to be used, because the Duke of Wellington liked to make a wound he could put his thumb into. The idea was a very ingenious one; it was simply a belt round a common bullet so that the soldier might put the bullet in either way, *Fig. 8*. The barrel-rolling machine was a very pretty thing, very like a long wire-rolling machine for telegraph wires. The rolls were alternately vertical and horizontal; it was an excellent tool for turning out large quantities. The pressure was so great that the barrel, like the wire, kept hot whilst being rolled. He took some interest in the rifling-machine, having made machines for the late Mr. Charles Lancaster, both for small arms and large guns. The Crimean War was the first occasion on which rifled guns had been used in Her Majesty's service, the weapons being Lancaster oval-bored guns. There were some defects about the

Fig. 7.

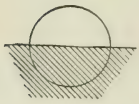
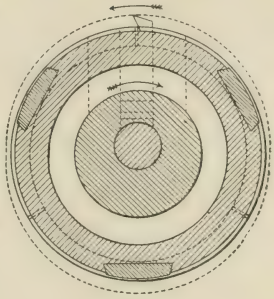


Fig. 8.

gun; there was an increase in pitch which was very objectionable, but it had a smooth-bore which was fairly free from fouling. The French general sent round to an English general to ask him to put a few shots into a Russian battery. The very first shot opened up the embrasure, and the second shot knocked over the gun and gunners. The Emperor of the French adopted rifled guns from that moment. The way in which the gun was bored was shown in *Fig. 9*. The rifling-tool for large guns, 68-pounders, for instance, was, in fact, an epicycloid tool composed of a revolving shaft carrying one cutter inside a hollow shaft, eccentric to it, which revolved the other way, so that the one tool projected out twice, and was withdrawn twice in every revolution, thus describing an oval. This machine bored the first rifled guns ever used in the service. The oval bore was produced in small arms by a cutter in a cutter-box, similar to that exhibited by the Author, but taking one-half of the barrel at a time. He was glad the Author had pointed out why breech-loaders could now be made so efficient, viz., by the use of a complete lining of the breech end by the metallic cartridge. He was present in 1860 when, in that room, the late Sir Joseph Whitworth brought forward his partially-covered metallic cartridge. The late Mr. John Anderson, who was sitting next to him, was delighted with the idea, and still more when told that it was then five years old in Prussia. The idea was that of a saucer or bush inside the gun, of which the powder was fired. That bush, being of metal, could not pass through the crack or small slit between the breech-plug and the gun. Powder-smoke might not get through on the first or second rounds, but after a dozen rounds it would get through any crack. The metal could not pass through; and the shot was fired out of the metal. The metallic cartridge had been the means of enabling breech-loaders to be used, either of large or small bore. He was very glad that the Author had pointed this out. He did not remember to have heard it mentioned in public before; but directly he saw the cartridge he perceived its object and use.

Mr. Cowper.

Fig. 9.



Dr. C. S. Du Riche Preller desired to briefly refer to the Government small-arms factories and the magazine-rifles of Italy and Switzerland, with which he had recently become incidentally acquainted; he had also had frequent opportunities of conversing

Dr. Du Riche Preller.

Dr. Du Riche Preller.

with Italian and Swiss officials on the subject. The Italian factory was situated at Terni, about 50 miles north of Rome, and half-way between the Mediterranean and the Adriatic, at the confluence of the two rivers Nera and Velino. The factory derived its motive power from the falls there. The machinery, chiefly supplied by Greenwood and Batley, was capable of turning out about 230 rifles per day. The wages ranged from 2*s.* 6*d.* for labourers to 5*s.* 6*d.* for foremen, for ten hours' work—piece-work earnings being equal to about 3*s.* 6*d.* per day. The Swiss factory was situated at Berne, and was worked by steam. The factory employed at present about 400 men, the rates of wages and earnings by piece-work being about the same as in the Italian factory, from which it differed, however, in this respect, that at Berne the work was limited chiefly to fitting and finishing the different parts of the rifles, supplied by another federal factory near Schaffhausen, as well as by several private Swiss firms. That system had its advantages, but it increased the cost of the rifle; the more so as the smaller private factories were insufficiently provided with machinery. The new Italian magazine-rifle, 5 cartridges, was the so-called Turin model of 1891; it had the smallest bore (6·5 millimetres) and greatest initial velocity (2,200 feet per second), and was the lightest of any of the European Government rifles. The new Swiss rifle, 12 cartridges, introduced by Colonel Schmidt, Director of the Federal factory, was the 1889 model, and had a bore of 7·5 millimetres, and a muzzle-velocity of 2,000 feet per second. Investigations and trials were now being made by Professor Hebler, of Zurich, and the Federal Government, to reduce the bore to 6 or even 5 millimetres, with every prospect of success; and it was not difficult to foresee that the other powers would soon have to follow the example of Italy and Switzerland. As to the cost, it had been stated that the French rifle, exhibited by Colonel Hemans, cost 60 francs, or £2 8*s.* The new Italian rifle would cost only £2, exclusive, however, of charges for interest and depreciation; the Austrian cost £2 12*s.*; the German, £2 13*s.*; the Mauser, £2 18*s.* The Swiss rifle cost at first £3, then £3 4*s.*, and now £3 10*s.*, while the cost of the Lee-Metford was £3 12*s.*, so that the last was the most costly of all. That fact had been attributed by Dr. Anderson to the shorter hours and higher wages in this country; who stated, moreover, that of the £3 12*s.*, only 9*s.* represented material, the rest representing labour. Dr. Preller ventured to submit, from his experience in other branches, that the difference between the cost of labour in this country and on the Continent was, at the present day, not nearly so

great as was generally believed. Any advantage of lower wages and longer hours on the Continent was much neutralized by the numerous public holidays, more especially in Roman Catholic countries, no less than by the regulations of labour, and by higher direct taxation; whilst in such countries as Italy and Switzerland, it was more than neutralized by the want of coal and iron, seeing that imported bituminous coal or briquettes cost as much as 30*s.*, and Scotch pig-iron 70*s.* a ton. The charges of manufacture, which, in his opinion, conduced much more than mere labour to unduly enhance the cost of British as compared with Continental productions generally, were, administration, management, superintendence, and margins of profit. With reference to the first three items, it would be instructive if Dr. Anderson would give, for comparison of private with Government factories, an analysis of the £3 12*s.* cost of the Lee-Metford rifle; and, as to margins of profit, Dr. Preller had a shrewd suspicion that the trade in which Colonel Hemans was interested, not infrequently overreached itself by excessive margins. With regard to the unfavourable opinion in France in relation to the Lee-Metford rifle, he was not at all sure that it was unbiassed; he could only say that, both in Italy and Switzerland, he had heard the Lee-Metford rifle repeatedly described, by competent authorities, as a good and highly-finished, but costly, weapon, although, not being strictly a magazine-rifle, it was behind the latest patterns of other nations. On the other hand, he endorsed most emphatically Colonel Hemans' remarks with reference to the rifle-trade being driven from this country by the impossibility of British private manufacturers competing with Continental and American makers. Speaking from his own experience, any desire to give a preference on the Continent to English manufacturers, except in some specialities, was in the present day almost invariably wrecked, not only on their prohibitive prices, but on their inveterate unwillingness to adapt themselves to cosmopolitan standards and requirements.

Dr. Du Riche Preller.

Mr. C. Frederick Lowe observed that the Author, and he thought General Arbuthnot also, had told them that the life of a barrel as now used in Her Majesty's service was only 3,000 rounds. On the other hand, some years ago, Mr. Gibbs, a gunmaker of Bristol, fired 50 consecutive shots at 1,000 yards with a Metford rifle manufactured by himself, which had already fired 15,000 rounds, and, in the presence of Sir Henry Halford, had put 50 consecutive shots into a 4-foot circle, and forty-eight shots out of that fifty into a 3-foot bull's-eye. That was an example of the

Mr. Lowe.

Mr. Lowe. life of a barrel of the old pattern. That life was now reduced to 3,000 rounds, which was a very serious question. Under those circumstances, Mr. Lowe had ventured to enquire of Mr. Maxim, what was his experience with reference to the life of a machine-gun with the new style of bullet. Mr. Maxim's reply was:—

> "In my experiments with the Austrian (Maxim) guns in which the envelope of the bullet was that of steel, I found that an ordinary soft-steel barrel, such as used in rifles, would only fire about three thousand rounds if fired quickly. Upon making the barrel out of steel that had sufficient carbon to admit of its being tempered, and having it tempered from the inside, twenty thousand rounds were fired before the accuracy of fire began to fall off. However, when a large number of guns had been delivered, and the men had become very expert at firing, they could succeed in changing the boxes so quickly as to keep the gun practically firing all the time. The result was that the barrels became used up at ten thousand to twelve thousand rounds, but this was clearly the result of the intense heat just forward of the cartridge case. At eight thousand rounds an enlargement commenced, while at about twelve thousand it became scooped out egg-shaped, until the gases passed around the projectile and the recoil fell off so that there was not sufficient energy to work the gun. I have not witnessed any protracted experiments with cartridges covered with German silver or nickel. In Austria I should say that about half a million cartridges were fired."

He ventured to submit that attention should be paid to this in the manufacture of rifle-barrels at Enfield. With regard to the question of bullets, the Germans used a steel-clad bullet which was soldered to the lead core inside, so that it was a solid homogeneous mass. That bullet was not a cylinder—it was not the same size all the way up, so that it only bore upon the rifling for about a quarter of its length, and the result was that there was considerable diminution of friction. He had made some experiments, and found that, in firing ten German bullets, there was a diminution of temperature of 1° F. for every shot fired compared with Woolwich bullets. It therefore appeared that if the military authorities would adopt the German pattern of bullet in preference to the Woolwich bullet, the barrels would last much longer. With the present bullets, the friction was sometimes so great that the lead was frequently melted during the passage of the bullet up the barrel. The higher the velocity, the greater the tendency of the lead to melt. The problem of a satisfactory bullet had, in his opinion, been solved by the British Munitions Company, who made a steel-clad bullet with a solid base and a soft lead point, so that, if the lead melted it was bottled up, and the soft point "mushroomed," and would pierce a steel plate inclined at such an angle that a Woolwich bullet would glance from it.

Mr. Stromeyer. Mr. C. E. STROMEYER believed he was correct in assuming that, neither before nor after straightening, were the barrels annealed,

and he felt convinced that, under these circumstances, the most serious strain must still exist in the metal. He should like to know whether the bad performances with old rifles was due entirely to wear in the bore, or whether it might not, to some extent at least, be accounted for by an un-twisting or un-bending of the barrel, due to occasional over-heating. If that were so, then the serious danger existed that, after being fired rapidly from the magazine, some of these rifles might twist a little and be worse than useless for long ranges, at least until re-sighted. It had been ascertained by Mr. J. Wehrenfening[1] that steel bars, if heated to redness for 72 hours, shortened $\frac{1}{2}$ per cent., while permanent changes of form were noticeable even if the temperature did not exceed that of boiling water; and, as rifles might easily become heated beyond that point, Mr. Stromeyer thought that they should be annealed. If it were impossible to do this at a red heat, it might at any rate be advisable to warm the barrels to the highest temperature that they would attain in service. He might mention the process of annealing said to have been successfully adopted by Messrs. Schott Bros., of Jena, for removing the last traces of strain in optical glass. Instead of heating and cooling lenses slowly, they were first heated as usual, and then cooled step by step from one temperature to a lower one, and maintained at each point for a long period of time, in order that the centre of the glass might acquire the same temperature as the outer surface. Everybody conversant with the operation of flanging boiler-plates would know how serious were the deformations experienced during the subsequent annealing, even though all the bending had been done at a red heat. That was particularly noticeable with flanged furnace-front plates, the holes in which invariably grew oval, the difference between the diameters sometimes amounting to as much as 1 inch. In his opinion, the cold-straightening of the gun-barrels would have relatively even a worse influence. Another matter in which he had taken a great interest was the bursting-strength of gun-barrels; and he had stated his views on that subject in the course of the discussion upon Colonel Eardley Maitland's Paper on "The Treatment of Gun-Steel."[2] Those views were subsequently fully confirmed by the bursting of a solid steel gun; and, more recently, he had obtained a piece of a steel shell which had been shattered by one

Mr. Stromeyer

[1] Organ f. d. Fortschritte des Eisenbahnwesens, Wiesbaden, 1884, vol. xxi., p. 222.

[2] Minutes of Proceedings Inst. C.E., vol. lxxxix. p. 177.

Mr. Stromeyer. of the new violent explosives. *Fig. 10* was prepared from a photograph of the sample, and represented the inner surface—the sheared surfaces could be distinctly seen on the left of the figure. *Fig. 11* was a section through the line A A, and *Fig. 12* was a section through B B, and showed that on one side the line of shear was in one direction, whilst the other was at right-angles to the first. These two cases of rupture had convinced him of the correctness of his mathematical deductions, viz., that the strength of a gun-barrel depended not on the tensile, but on the shearing strength of the metal. The latter, it was well known, was about 20 per cent. less than the former; and, according to the diagrams of the powder-pressures, *Fig. 5*, every Lee-Metford rifle ought to

Fig. 10.

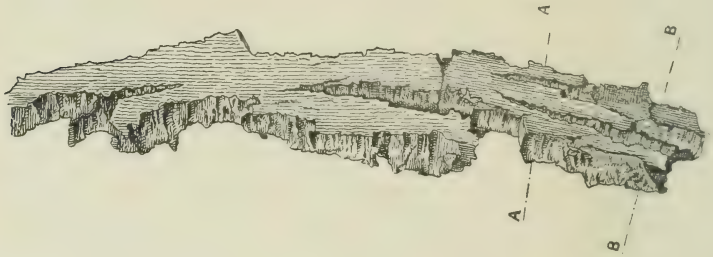


Fig 11.

ENLARGED SECTION AT A A

Fig. 12.

ENLARGED SECTION AT B.B

burst every time that it was fired. As that was not the case, he disbelieved the diagrams altogether. The method of obtaining them seemed to him unreliable, and he could not understand why a simpler one was not adopted. He remembered having designed an instrument for this purpose some years ago, but the matter ended there; for the highest authority on guns in those days told him that everything that was needed to be known about powder-pressures and stresses was then already known.

Mr. Mole. Mr. FREDERIC M. MOLE, as the representative of the Birmingham firm of sword-cutlers referred to in the Paper, wished to say a few words on the subject. First as to General Arbuthnot's remark,—that Mr. Mole had said they would never succeed in making swords

at Enfield. He could not have made so presumptuous a statement. With the vast resources of Enfield, with skilled foremen in every department; with no fear of bankruptcy to stare them in the face, he should have no doubt as to their succeeding eventually in anything they undertook to make. Another mistake was as to their not having made cavalry swords at Enfield. He had seen them many years ago with the Enfield mark upon them, and one of their forgers, after leaving, worked for his firm for a short time; since then, he had seen Snider sword-bayonet blades being forged at Enfield, and they were really only a short cavalry blade. But being dependent for sword-work almost entirely upon the War Office, it was quite possible he might have said: "I hope you will not commence sword-making at Enfield, and so take our little trade away from us." As to the sword-trade, it had never, so far as he was aware, been carried on at Sheffield, and it was only comparatively recently that sword-blades had been made in London. The London sword-cutlers were formerly supplied from Birmingham with the blades and scabbards they required. His father established a business there nearly 60 years ago; and for 40 years Mr. Mole had been actively connected with it. For nearly that length of time he had had the practical management of every department, and they had made more swords for the Government than any other English maker past or present. But the trade had never been a self-supporting one: there had been busy times, the Crimean War being the most important one; but there were long intervals of stagnation. About 30 years ago, there were four or five names of Birmingham sword-contractors on the War Office list, but the Government demand fell off, the London houses who had formerly had their blades and scabbards from Birmingham went to the Solingen makers; a great portion of the private and export trade fell into the same hands; one by one the several makers died out, and it was only the matchet trade that saved his own firm from the same fate, as, although for nearly 20 years, and up to quite recently, they executed the whole of the Government orders for swords, there were long periods when they were not sufficient to keep one sword-forger half employed, and it was with the greatest difficulty that they could keep even the smallest staff together. Was it surprising, under the circumstances, that they were unable to meet the large and sudden demand for the 1885 cavalry sword, to the extent required? He thought General Arbuthnot might have explained that matter, and might also have mentioned that the new pattern made while he was superintendent at Enfield, had two important improve-

Mr. Mole.

Mr. Mole. ments in the scabbard, and one in the hilt, which were Mr. Mole's invention. Those in the scabbard had been used in the previous pattern; but that in the hilt, called the hand-rest, was one made to meet a defect that Colonel King Harman had said he considered the cavalry-sword had in the grip. Mr. Mole had submitted to Enfield a sword with that improvement previously, but heard nothing about it until some time afterwards, when he first saw the new pattern, and then found, to his surprise, that it had been introduced. He did not find fault for the rolling-machine having been set up at Enfield, so as to enable any sudden emergency to be met without going abroad; but he thought, under the circumstances of the trade, it ought to be confined to that purpose; and that it would be very hard on them after their many years of faithful service, and after having surmounted the difficulty they had at first with the blades, if the manufacture of the cavalry swords and the naval cutlasses, the only patterns ordered in any quantity, was to be confined to Enfield, as had been the case during the last year or two.

Dr. Anderson. Dr. W. Anderson proposed to add very few words, as Captain Nathan had stated almost all that he had intended to say with reference to foreign rifles. There could be no greater authority on the subject, because it had been Captain Nathan's duty for many years to collect all the information available relating to small arms, and to examine and report upon the various rifles submitted to the War Department. The impression his speech must have produced was that, however benighted they might be at the War Office or at the Ordnance Factories, at any rate they kept their eyes open, and watched what their neighbours were doing, and endeavoured to pick up the best information for the use of Her Majesty's Service. As stated by General Arbuthnot, it was not considered desirable that rifles should be so constructed that soldiers could easily take them to pieces. The War Office had aimed at putting into their hands weapons which should never get out of order, and he thought that it had succeeded in doing so. Any weapon like the rifle produced by Colonel Hemans, which required the soldier to carry two spare extractors, would not be considered for a moment, seeing that failure to extract the spent cartridge meant the practical disablement of the arm. He marvelled at Colonel Hemans' ingenuousness in putting forward so innocently the defect of the Berthier rifle, to say nothing of demonstrating in a striking manner, by the way in which he took the action to pieces and then struggled to put it together again, the consequences if a soldier should attempt the

same feat in the field or even in camp. He regretted that Colonel Hemans had not satisfactorily answered the two questions put to him. Among all the defects with which the magazine-rifle had been credited, he never before heard of its possessing the fascinating powers of a poisonous snake; but, according to Colonel Hemans, this rifle had so fascinated the British gun-makers that they were utterly unable to produce anything less defective, simpler, and cheaper, than the magazine-rifle. That certainly was a very curious result, but it was the only construction he could put upon the statement which Colonel Hemans had made, that the introduction of the magazine-rifle had practically ruined the British gun trade. The other question he had asked was what the Berthier rifle would cost if made in England. He did not think Colonel Hemans was quite ingenuous in comparing the two arms. The Berthier rifle, or rather, carbine, had 4 cartridges in the magazine whereas the Lee-Metford had 10, with an arrangement to convert it into a single loader at any moment, a very material difference. Then, with regard to the cost, Dr. Preller had stated that the wages in Italy and Switzerland ranged from 15*s.* to 33*s.* for a week of 60 hours, whereas the average rates of wages at the Enfield factory were, for a week of 54 hours, 31*s.* 6*d.* to 45*s.* for skilled mechanics, 13*s.* 6*d.* to 27*s.* for boys and machine men, and 19*s.* to 27*s.* for labourers, while the piece-work earnings were about one-third more. It could easily be seen that the shorter hours, and the higher price of labour must be a very important factor in preventing English gun-makers from obtaining Continental orders, the home trade, of course, being insufficient to employ very large factories. Mr. Lowe, in speaking of the endurance of rifle-barrels, had forgotten to mention that the 16,000 rounds were probably fired with black powder, whereas the 3,000 rounds were fired with cordite. There was an essential difference in the wear of barrels, according as black powder or cordite was used. As far as experiments in progress went, there did not appear to be any advantage derived from hardening the steel of the barrel. Trials were being made, to ascertain what really would increase its durability, either by modifications in the bullet, or by treatment of the bore; but they had not yet arrived at any satisfactory result. With regard to Colonel Hemans' remarks about cordite, it was extremely unfortunate that a gentleman, who had once been an officer in Her Majesty's service, an assistant-superintendent at the Gun Factories, and a Proof Officer, should have advanced such a loose statement upon that exceedingly important subject. With every opportunity of ascertaining the facts from authentic sources, Colonel Hemans

Dr. Anderson.

Dr. Anderson. had preferred to take his information from a pamphlet which Dr. Anderson had never heard of before, and he had handed it in to the President as a work published by authority, and representing the true composition and nature of cordite. That pamphlet, he had since discovered, was written by a Professor of Chemistry at the Military Academy at Woolwich, and consisted of notes on lectures on explosives, and contained only one brief allusion to cordite; it was written in 1891 when cordite was not a service article, and the notice was outrageously wrong, because it made camphor one of the ingredients. If there was one thing which the inventors of cordite had most studiously tried to avoid, and the fact was known to every one who knew anything about the subject, it was camphor, because when that volatile substance formed one of the ingredients of smokeless powder, the latter would not be permanent in composition, but would be subject to variations due to time and to climatic changes. Consequently, the explosive which Colonel Hemans talked about was not the cordite which had become in many respects the service-explosive of the Army and Navy, but was a totally different substance, quite unfit for their use. Also, he thought Colonel Hemans ought not to have mentioned the French gossip about the small changes in the density of the cordite being sufficient to blow a gun to pieces. French officers whose opinions were entitled to respect knew perfectly well, as Colonel Hemans must also have known, that black powder, as well as cordite, had to be of a size and density suitable for the gun. If they tried to fire rifle-powder in a 16¼-inch gun, the consequence would be disastrous; and so would firing small cordite in a large gun. There was a gravimetric density for black powder which must not be exceeded in a gun of a given strength; and there was a gravimetric density for cordite which likewise must not be exceeded if a given pressure was not to be surpassed. Within those limits of gravimetric density, they might vary at pleasure without the smallest danger. Although they frequently had abnormal pressures with black powder, he could not recall a single instance of abnormal pressure with cordite, when fired under normal conditions. Therefore he did not think that the new explosive was so liable to capricious variation as black powder, and consequently, the criticism which they had heard upon it was not justified, and ought not to have been introduced. He should be very glad to give any detailed information about the cost of the rifle, which might be thought instructive. He presumed that the cost of management and administration, to which allusion had been made by Dr. Preller, referred to private manufacturers, because it certainly did

not apply to Government factories. He supposed the prevalent idea was that Government factories were overwhelmed by numbers of useless salaried officials; but, as a matter of fact, those who knew something about the administration of works would, perhaps, be surprised to hear that the total cost of administering the Royal Factories was only $\frac{1}{2}$ per cent. upon the value of the production; whereas the benevolent part of the administration—medical aid, sick-pay, injury-pay, and pay for holidays—amounted to about $1\frac{1}{2}$ per cent. Adding even that, their total expenses were less than 2 per cent. upon the cost of their manufactures, therefore he did not think that management-charges were the cause for the apparently high price of the magazine-rifle. Dr. Anderson.

Mr. Rigby, in reply, said he almost felt that he owed an apology to the Institution for reading a Paper which had introduced with it something like an apple of discord. He would not touch on that subject; he had stuck to his text from the beginning, and, if they would allow him, he would do so to the end. If, as Sir Henry Halford had said, he had not done justice to the Metford rifling, it was because his wish had been to avoid all questions of pattern, and to confine himself as much as possible to manufacture. He had not mentioned, either with praise or blame, other features of the Lee-Metford system, as, for instance, the breech-loader and magazine. The labours of Mr. Metford in the field of rifle-manufacture, particularly the rifling and ammunition, gave him an undoubted claim to public recognition and reward; and it was much to be regretted that his state of health had prevented him from taking part in the present discussion. As to the use of the lap and emery after rifling, he could not agree with Sir Henry Halford, who argued from the abuse against the use. Properly applied, the lap did not do the harm he apprehended; it was not resorted to to conceal bad work, but to remove any possible burr, and to give a polish by means of which the minute defects in the steel were, if any existed, more easily detected. It was no argument against its use in a rifle-barrel that one did not use emery to finish a surface-plate. It was used to finish a gauge-plug requiring much more accuracy than a rifle-barrel. The criticism on the method of taking pressures by the shortening of a copper plug, was answered by appealing to results in the absence of a better method. Pressures computed by observing the increment of velocity in various parts of the bore did not show any great discrepancy from those obtained from the crusher-gauge. Again, proof of pressures recorded by the latter were confirmed by the behaviour of steel whose yield-point was known. The use of Mr. Rigby.

Mr. Rigby. the crusher-gauge required, however, certain precautions, without which its indications were misleading. He observed that Dr. Anderson was not prepared to assent, without further evidence, to the superiority claimed for the Enfield system of forging rifle-barrels by rolling. He said that at Sparkbrook they were forged under hammers. At Steyr and Liège they were also drawn out under hammers. In Berlin, however, all the barrels of Government rifles were wrought by rolls. The process was different from that at Enfield. The machines were more like the segmental rolls that were used for sword-blades. The bars were heated twice or oftener, and rolled to an octagonal section. The machines were the invention of Marcotty & Co., who produced the forgings from bars of Krupp steel. The Germans attached much importance to this system of compression, as they call it. Messrs. Marcotty gave the following figures as the result of their process :—

	Elastic Limit.	Breaking Stress.	Elongation.	Contraction of Area.
	Tons.	Tons.	Per cent.	Per cent.
Steel before compression . .	23·6	44	19	39
„ after „ . .	37	51	11·5	39

He had found at Enfield, by taking test-pieces from the bars before and after rolling, a considerable increase in the stiffness and strength of certain qualities of steel, though not to the extent claimed by Messrs. Marcotty. With reference to the Sparkbrook Factory, the works were built by the National Arms Company (Limited), and equipped chiefly by Messrs. Greenwood & Battley, of Leeds, for the manufacture of the Martini-Henry rifle, the patents for which were the property of the Company. They entered the European market to obtain contracts for large supplies. A Turkish order for 500,000 was confidently expected. Vexatious delays occurred, and, at the last moment the order was given to the Providence Tool Company, U.S.A., which had not, up to that time, engaged in the manufacture of arms on a large scale. No large foreign order for Martini-Henry rifles was obtained, but an order for 100,000 needle-rifles for the Prussian Government was executed, and some orders for Martini-Henry rifles from the Home Government were later received. The Company then went into liquidation, and the share capital was lost. About 1886, the War Office purchased the buildings and plant, and transferred from

their premises in Bagot Street, Birmingham, to Sparkbrook, the work of repairing arms and training armourers. Those premises were afterwards offered for sale, and the Sparkbrook factory was subsidiary to Enfield, and was administered by the superintendent there, aided by an assistant superintendent, resident at Birmingham. It was proposed to do revolver-work, and possibly to make carbines, at Sparkbrook, so as to relieve Enfield, where there was not room for them in the event of an urgent demand for rifles. That was the state of matters when he was appointed superintendent in 1887, with charge of both factories. Two months afterwards, all the Ordnance Factories were placed under a Director-General, with central Offices at Woolwich. The Sparkbrook factory was separated from that at Enfield. The assistant superintendent, Colonel McClintock, R.A., received the rank of superintendent, and the Secretary of State decided to employ the factory in repairing arms as hitherto, in the conversion of arms, and in such other work as could not be conveniently undertaken at Enfield—the latter factory to be exclusively employed on new arms, and in repair of machine-guns. In those arrangements Mr. Rigby concurred. About eight months afterwards they were upset. The Secretary of State withdrew the Bagot Street premises from the market, re-placed there the repairing- and armoury-staff, and decided to fit up Sparkbrook for the manufacture of the Lee-Metford rifle, to turn out about 700 per week—thus establishing a second rifle factory competing with Smallheath and Bow for the Government orders. The system of manufacture at Sparkbrook was in general similar to that at Enfield, and the cost was about the same also. With regard to the erosion and wear that rifle-barrels and quick-firing guns underwent through the use of cordite or other powders, Dr. Anderson had appealed for assistance in counteracting their destructive agency to the eminent consulting engineers of the Ordnance Committee, and in doing so in this public manner had made a wider appeal. He had made known the want of a less easily eroded steel to many of their scientific metallurgists, who would probably otherwise not have had their attention directed to the subject; and Mr. Rigby heartily hoped the result might be a readier solution of the problem than might otherwise have been attained. That illustrated the advantage of publicity. He could not agree that the official handbooks gave all the information that outside inventors ought to have. They were not often enough revised for that purpose. An annual progress report, as published by the United States War Office, would more nearly meet the case. To give one more illustration of what he meant. The United

Mr. Rigby.

Mr. Rigby. States had a small-arms committee, which, in August, sent in their report of conclusions, and their reasons. In September, the document was published in the New York technical journals, and was known all over Europe early in October. His proposal to afford an official trial to inventors did not contemplate so wide a field as Dr. Anderson had assigned to it. Limits could be put, within which much useful work might be done. As an illustration, orders could not now be booked in England for rifles carrying service 0·303 cordite ammunition, which, as yet, had not been produced by the trade. There were, however, manufacturers of smokeless powders offering ammunition with good ballistic properties. The certificate of an impartial committee that such ammunition satisfied the conditions essential to military use, along with sufficient accuracy, would possibly remove the formidable impediment to trade in these arms. The remarks made by Colonel Hemans on cordite, showed that the properties of the explosive were not accurately known by him, and that he had been rather misled than instructed by what had been published on the subject. Captain Nathan had dealt with Colonel Hemans' remarks as to systems and patterns. As to price, Colonel Hemans had quoted 60 francs—say 48*s*.—as the price at St. Etienne, of a Berthier carbine of the French Government pattern, and had said that magazine-rifles in other parts of Europe cost less. He did not know his authority for the French price. If it was the price given as the cost at the Government factories, he should like to know whether, as in this country, all the charges for administration, capital and machinery, were added to the direct cost of material and labour. He rather thought they were not. As a comment on his proposal for an authoritative trial of inventions and productions, Colonel Hemans had said the best certificate of excellence would be adoption by the Government. He did not, surely, propose that there should be a change of pattern, with all that it involved to the tax-payer, whenever a new rifle had been proved to be a little easier to dismount than the service-rifle. He had been asked by Mr. Woods to admit that he had been less than just to the Birmingham gun-trade. It was true that the production, during the Confederate war, was large. There were buyers in Europe for almost every one of the dis-United States. The price of Enfield rifles (the pattern of that day) was forced up. A fever of production was the consequence. There was no machinery to run night and day. Nearly all work done by hand, excepting the manufacture of barrels, and for those the machinery was poor. Rifles were made

in large numbers of very indifferent quality, and at very high prices. The experience of that crisis was enough to prevent foreign States from again relying on Birmingham to supply them in cases of need. It was in that sense that he maintained that the failure of the leading small-arms contractors in Birmingham, to meet the demand then made on them for a good rifle, at a fair price, was so prejudicial to the foreign trade of Birmingham in military arms. He was sure the Institution appreciated General Arbuthnot's contribution to the discussion. His long experience at Enfield give authority to his remarks. During his term of office as superintendent, the Factory was considerably extended and new branches of work undertaken. In reference to the specification for barrel-steel, he was glad to inform General Arbuthnot that they not only had specifications, but had added a chemical laboratory and a testing-room since 1888, under the charge of Mr. Kinsley Doyle. The testing-room was fitted with a 50-ton Buckton machine and other apparatus; and there was now no necessity, as formerly, to send test-pieces and samples of steel or other stores that required chemical examination to Woolwich for that purpose. General Arbuthnot's remarks on the manufacture of swords at Enfield showed the proper function of a Government factory. The work had been taken up at a time when it seemed as if, otherwise, England would have become dependent on foreign supplies whenever a large number of swords were needed, a state of affairs that should never be tolerated. Before leaving the subject, he wished to say that, although sword-blades were first rolled under segmental rolls at Solingen, the credit of introducing the system was really due to a former manager at Enfield, Mr. Barnes, who invented and patented this method of making triangular bayonets. Its application to sword-making at Solingen was subsequent to the time of Barnes' patent; and still later, it was introduced at Enfield for sword-forging, in 1889. In speaking of swords, Sir Benjamin Baker had paid a high compliment to the form of blade arrived at tentatively. In designing a blade, as in making a flat spring, the first made was bent after it had been tempered, and the curves assumed by it were observed. A place where undue stress was thrown on the material, showed excessive curvature. The spring-maker did not know the "bending moment," or "moment of inertia" of the section; he said it "buckled," and proceeded to make another blade thicker at that place, or to grind or file down the more rigid parts until the whole assumed a curve that satisfied him. The Civil Engineer followed and measured the sections all along the blade. He took his modulus of elasticity, his moment

Mr. Rigby.

Mr. Rigby. of inertia and radius of curvature, computed the stresses on the molecular structure of the metal, and found that on the whole they were fairly distributed along the blade or spring. In the case of a sword-blade, other and conflicting conditions of cutting-power, stiffness for thrusting, weight, and balance, had to be observed. One could not alone keep in view a uniform surface-tension all along the blade when bent. The relation of surface-tensions and compressions to bending was not quite satisfactorily dealt with by the ordinary engineering formula. Mr. Rigby exhibited a drawing of a blade under the bending test, that figured out to a stress of 107 tons per square inch at one place, and yet that blade recovered straightness when released. It would, indeed, bear a little further shortening before bending, and nearly double the curvature before breaking. What kind of material was it that endured those stresses of 107 tons per square inch within its elastic limit? And if they are outside its elastic limit, why did it recover straightness? He left those questions to Civil Engineers. He hoped gentlemen who had spoken would excuse his not going into all the questions raised by them, because, as he had said before, he wished to adhere, if possible, to the subject of the Paper, namely, the manufacture, and not the pattern, of small arms. In reply to Mr. Lowe, however, he must deny having stated that 3,000 rounds was the life of the Lee-Metford barrel. He thought they might consider the life of the barrel to be considerably more than that, but, at all events, he had not made such a statement. In another connection, altogether, Dr. Anderson had made some statement of that kind. As to the statement about friction melting lead in the passage of the bullet through the barrel, he did not believe any such thing had ever occurred. In answer to Sir Benjamin Baker's remark on the remoteness of the Manufacture of Firearms and the Paper generally from the interests of the Institution, he admitted that the discussion had discursed to topics more of Military than of Civil Engineering; but that could hardly be said of the Paper. Yet he thought the Institution seemed more interested in the discursions than in the text. He held, however, that Civil Engineers, when they applied their knowledge of mechanical principles and of materials to the assistance of manufacturers, were fulfilling their proper functions—whether it were a question of war or peace, of great guns or great bridges, or even of cavalry swords.

Correspondence.

Mr. J. D. Goodman desired to correct a statement made in the Paper to the effect that when the English War Department had furnished the Government factory at Enfield with complete machinery for producing arms on the interchangeable system, the Birmingham contractors were slow to follow the example thus set. Enfield made the first preparation to produce arms by machinery in 1854, and made the first guns on this system in 1858. The military-arms traders of Birmingham had formed themselves into an association in 1855, during the Crimean War, and appointed Mr. Goodman their chairman in January of that year. In 1857, the association purchased from America the machinery required for forming the gun-stock. After working this for a time, they found that, to work profitably, they must make the entire gun by machinery. They formed a company in 1861, and, in June of that year, ordered a complete set of machinery from America. In consequence of the war which broke out in the United States, the order was cancelled, and was transferred in October, 1861, to an English manufacturer. In 1862, 26 acres of land were purchased, and the present factory was erected. With the subsequent extensions it contained, in 1892, an available floor-space of 157,000 square feet, and was capable of producing 1,250, and had actually produced 1,000 magazine guns per week, in addition to other munitions of war, such as quick-firing shells, &c. The first guns made in the factory were turned out in June 1865. The Author's statement that the demand for rifles for the United States, during the Civil War, found the Birmingham contractors quite unprepared, and that they utterly failed to meet the demand, must have been made in ignorance of the number of Enfield rifles supplied to the Northern States by Birmingham at that time. The association commenced supplies in May 1861, and continued to make deliveries till the quantity exceeded 10,000 rifles per week. In December 1861, so large were the transactions, that he felt it his duty to report them to the War Office; on the 5th December, 1861, an embargo was laid on the export of arms. The embargo was removed early in 1862, and, immediately afterwards, one steamer took out from Southampton nearly 40,000 rifles to New York. He quoted

Mr. Goodman.

Mr. Goodman. the following from a Paper published by him in the journal of the Statistical Society in December 1865 :—

"I find, by the return from the Birmingham Proof House, that in one month, the month of October 1863, sixty-thousand three hundred and forty-five rifle-barrels were proved, being very few short of two thousand per day from Birmingham alone, a number altogether unprecedented in the history of the trade. From the Proof House returns for the four years, 1861 to 1863 inclusive, I obtain the following numbers, showing the extent of the supply of arms from this country to America during the war—

Birmingham supplied	733,403
London supplied	344,802
Making a total number of Enfield rifles sent to America	1,078,205

It had been further stated by the Author, that the loss of the military-rifle trade with foreign countries might be dated from the time of the failure to supply arms to the Americans. As he had shown that no such inability existed, he would only add that, during the few months between 1st September, 1870, and the 21st April, 1871, the association alone supplied 114,700 rifles to France, almost all of them Sniders, in addition to upwards of 180,000 Snider actions, to be made up into rifles in France. That total by no means represented the entire supply from Birmingham as there were several gun-makers, not members of the association, who were busy at the same time, and the Birmingham Small Arms Company was precluded from taking part in the foreign trade, owing to its engagements with the British Government. In addition, since the American War, the company had delivered 110,000 rifles to other foreign governments, and the National Arms Company of Birmingham had delivered 100,000. He gladly acknowledged the statement made by Mr. Rigby, to the effect that every assistance was given to small-arms manufacturers by the officials at Enfield in the execution of their contracts. They were freely admitted to examine the Enfield machinery, and patterns and gauges were supplied to them when needed. At the same time, he might be excused, as one who had been concerned in the military arms trade, in different phases, for thirty years, if he showed jealousy at statements throwing doubt on the ability of Birmingham to meet any emergency that might arise.

Messrs. Weyersberg, Kirschbaum & Co. Messrs. WEYERSBERG, KIRSCHBAUM & Co., of Solingen, observed that their long experience had convinced them of the superiority of the system of the machine-forging of blades, introduced by them about twenty years ago, and adopted, not only at Enfield, but

almost universally, over that of hand-forging, which could not be relied upon where large quantities were required. With regard to hardening, their practice was to employ water for that purpose, as they found that when oil was used, the steel had to contain so much carbon as to be very brittle and unsuited for sword-blades. They attributed much of their success to the fact that their Government had not itself undertaken the manufacture of swords and similar weapons, but had hitherto found them work enough to keep their establishment fully employed, and encouraged them to constantly experiment and improve their manufactures. They found that solid-drawn steel scabbards, for both swords and bayonets, possessed considerably greater strength than the ordinary brazed kind. For these, they made an exceedingly thin cold-drawn steel tube by a process that so taxed the strength of the material, that only the finest quality could be employed. The first pattern of the scabbards made was worked up from this straight tube, but the appearance was so clumsy that they had found it necessary to experiment further, and had finally discovered a practical method of tapering the tube without diminishing its strength. Messrs. Weyerberg, Kirschbaum & Co.

Mr. RIGBY, in reply to Mr. J. D. Goodman, drew attention to the time, seven years, that had elapsed between the production of machine-made arms at Enfield by the Royal Small Arms Factory, and at Small Heath by the Birmingham Small Arms Company. He also referred to his reply to Mr. E. Woods' remarks. As to the manufacture of 210,000 arms for foreign Governments since the American War, he contrasts that with the operations of one American Company, Messrs. Remington, of Ilion, N.Y., who alone supplied about a million of these rifles to European States and to Egypt in the same period. Mr. Rigby.

LIST OF SMALL ARMS AND TOOLS

EXHIBITED IN ILLUSTRATION OF MR. RIGBY'S PAPER.

Exhibitor.	Objects.
BIRMINGHAM SMALL ARMS AND METAL COMPANY.	Magazine Rifles (Mark I and Mark II).
	Magazine Sporting Rifles (2).
COLT'S FIRE ARMS MANUFACTURING COMPANY.	"Lightning" Magazine Rifle with dummy cartridges.
	Skeleton of ditto.
	United States Government Revolver.
LONDON ARMOURY COMPANY. (James Kerr & Co.)	Model machine-made and interchangeable arms manufactured by the Winchester Repeating Arms Company.
LONDON SMALL ARMS COMPANY.	Component parts of Lee-Metford Magazine Rifle.
	Component parts of Martini-Henry Rifle in various stages of manufacture.
ROYAL SMALL ARMS FACTORY, ENFIELD.	Apparatus for testing straightness of bore mechanically with mirror micrometer.
	Stand for testing straightness optically.
	Barrels (12) of Lee-Metford Rifle in various stages.
	Gauges (103) of various patterns for components of Lee-Metford Rifle.
	Specimens (72) of components in various stages.
	Complete Rifles (2)—Lee-Metford, Mark II—in finished stage.
	Tools used in manufacture of barrels, viz., drill, 2 bits, and rifling cutter-box.
	Cavalry Sword, pattern 1890, in stages (2).
	Service Lances (2), bamboo.
	Sword Bayonets (2).
MESSRS. P. WEBLEY & SON.	Revolver, Mark I, and component parts.
THE WILKINSON SWORD COMPANY.	German Heavy Cavalry Sword with aluminium hilt and scabbard.
	Argentine Bayonet.
	Plug Bayonet (1670).
	Bayonet and Sword Scabbards.
	Trigger-Guard and Box for Magazine of Manser Rifle.

6 December, 1892.

HARRISON HAYTER, President,
in the Chair.

It was announced that the following Associate Members had been transferred to the class of

Members.

Charles Edmund de Bertodano.
St. George James Boswell, B.Sc.
George James Cottom Broom.
George James Clarke.
Gilbert Gilkes.
John Maitland Grant.
Edward Hayes.
Herbert Kyffin Heyland.
John Martin McCurrich, M.A.
John McLaren.
Frederic William Marchant.
Alexander Murray.
George Bernard Reynolds.
Lionel Barrington Simeon.
Walter Alexander Smith.
James Tait.
Charles Alfred Trery.

Also that the following Candidates had been admitted as

Students.

Dunstan Alfred Aeria.
Leonard Hodgson Appleby.
Stewart Armour.
James Edgar Askwith.
Francis Courtenay Atwool.
Granville Hugh Baillie.
Samuel Henry Barraclough, B.E.
Alban Francis Baynham.
Rowland Endicott Beavis.
Francis Bedford-Glasier.
Harold Berridge.
Harold Storr Best.
Charles Frederic Botley.
Charles Ernest Brackenbury.
John Barker Bradshaw.
Alexander Ernest Carroll.
Frederick Douglas Coleman.
Alfred Chorley Cookson.
Ralph Henry Covernton.
Louis Charles Croslegh.
Lionel Douglas Cross.
John Peachey Crouch.
Jonathan Roberts Davidson.
Sydney Bryan Donkin.
William James Dresden.
Herbert Ellis Duncan.
Edgar Mark Eden.
Charles Alexander Fleming.
Frank Furnivall.
Frederick St. John Gebbie.
William Henry Gittins.
Walter Burns Graham.
William Grant.
Charles Ernest Hall.
George Herschel Hamilton-Gordon.
Tom Shirley Hawkins.
Thomas Alexander Stewart Henry.
Frank Harvey Hummel.
Francis Inman.
Robert Jackson Kent.
William Henry Gustav Kieser.
Alexander Charles Hermann Laurie, F.C.H.
James Patrick Leslie.
George Ernest Lillie, F.C.H.
Guy Ernest Lloyd.
Charles William Alexander Orr Paterson McCormick.

Students—continued.

Alexander Roderick Mackenzie.
Ronald Brunlees McKerrow.
John Buchanan Marshal McMeekin.
Norman John Campbell MacTaggart, B.E.
Joseph Clarke Collins Martin.
Domingo Merry del Val y Zulusta.
Clifford Mitchell.
Hugh Henry Gordon Mitchell.
George Moncur.
Archibald Henry Morin.
John Turner Morris.
Ernest John Oakley.
Frederick Salkeld Page.
William Arthur Palliser.
James Henry Price.
James Waller Roberts, B.E.
Edward Charles Rodda.
William Herbert Shields, B.Sc.
Frederick Martin Short.
Philip Bertie Spencer-Stanhope, B.A.
Henry Alexander Stenning.
Charles Thomas Stephens, B.E.
George Harold Stevenson, B.Sc.
Ronald Cochran Stevenson.
James Frederick Alexander Stimpson.
Philip Francis Story.
Arthur Reginald Stuart.
William Sullivan.
Cyril Hanson Thompson.
John Thompson, Jun., A.Sc.
George William Volckman.
Ralph Watkin, A.K.C.
Thomas Aubrey Watson.
William Herbert White.
Alfred Arthur Williamson.
Oliver Winder.
Ronald Wyman.

The following Candidates were balloted for and duly elected as

Members.

John Bruce.
Charles Frederic Gilbert.
Gilbert Smith Goodwin.
William John Greer.
Arthur James Grinling.
Alfred Joyce.
John William Marley, A.K.C.
Thomas Morgans.
William Barclay Parsons.
Louis Penny.
James Perry, M.E.
Christopher Edward Phipps.
William James Pirrie.
Robert Brewster Stanton, M.A.
Addison Langhorne Steavenson.
John Thomas Wood.

Associate Members.

Alfred Seabold Eli Ackermann, Stud. Inst. C.E.
Affonso de Oliveira de Albuquerque-Maranhão.
Alexander Anderson.
Ernest Anson, M.A.
Harold Thomas Ashton, M.Sc., Stud. Inst. C.E.
Frederick Robert Bader, Stud. Inst. C.E.
Lewis Brown Bagot, Stud. Inst. C.E.
John Baker.
Francis Aloysius Bald.
Benjamin Ball, Stud. Inst. C.E.
John Henry Barker, Stud. Inst. C.E.
Ivan Collingwood Barling.
Reginald Clayton Barnby, Stud. Inst. C.E.
Sidney Walter John Barnes.
Arthur Robert Barrow.
Frank Edward Beadle, Stud. Inst. C.E.
Charles Vincent Bellamy, Stud. Inst. C.E.
Gerald Winzar Bennett, Stud. Inst. C.E.
Herbert Edwabd Bill, Stud. Inst. C.E.

Associate Members—continued.

William James Eames Binnie, B.A., Stud. Inst. C.E.
Norman Birnie.
Cyril Holm Biss.
Frank Walker Bottle, Stud. Inst. C.E.
Samuel George Brittain.
John Kempe Brydges, A.K.C., Stud. Inst. C.E.
Henry Frederic William Burstall, Wh.Sc.
Julian Edward Caccia, Stud. Inst. C.E.
Hugh Callaway.
Ralph George Carte, Stud. Inst. C.E.
Alfred Chatterton, B.Sc., Stud. Inst. C.E.
Edward Clarke, Stud. Inst. C.E.
Alfred Ernest Cochemé, Stud. Inst. C.E.
Adrian Charles Collins, A.K.C., Stud. Inst. C.E.
Ezekiel Grayson Constantine.
Charles Corner.
Sherard Osborn Cowper-Coles, Stud. Inst. C.E.
Frederick Nutter Cox, Stud. Inst. C.E.
Leopold Cust, Stud. Inst. C.E.
Henry Harvey Dare, B.E., Stud. Inst. C.E.
George Reginald Davey, Stud. Inst. C.E.
Frederic Brereton Dixon, Stud. Inst. C.E.
Robert Bland Dixon, Engr. R.N., Stud. Inst. C.E.
Stephen Mitchel Dixon, B.E.
Richard Frederick Drury, Stud. Inst. C.E.
Nicholas Dunscombe, Stud. Inst. C.E.
Thomas Frederick Ennis, Stud. Inst. C.E.
Arthur John Estcourt, Stud. Inst. C.E.
Robert Findlay.
Patrick Fletcher, Stud. Inst. C.E.
William Wellesley Pole Fletcher.
Colin Proud Fowler, Stud. Inst. C.E.
John Franklin Gage, Stud. Inst. C.E.
John Gandon.
Tom Gledhill.
James Kenneth Guthrie.
Daniel Meinerts Hahn.
Harry Hall.
John Ernest Harrison.
Thomas Hart, Stud. Inst. C.E.
Robert Falkland Harvey.
Joshua Binnington Henson.
Ernest George Hebbert, B.A.
Joseph Ball Hill, Stud. Inst. C.E.
Arthur Edwin Hopper, Stud. Inst. C.E.
Edward Morgan Hughes, Stud. Inst. C.E.
Edwin Human.
Daniel Lean Hutchison, B.Sc.
Harry William Maclean Ives, Stud. Inst. C.E.
Bernard Maxwell Jenkin.
William Eyre Kenny.
Francis Alexander Stuart King.
James Noble Kirby.
Henry John Lawson, Stud. Inst. C.E.
William Liddle.
Albert de Linde.
Robert Charles Lowry.
Edward Sydney Luard.
George Hutcheson McCowat, Stud. Inst. C.E.
Edward Charles Robert Marks, Stud. Inst. C.E.
Henry Hulbert Metcalfe.
Robert John Milbourne.
Ernest Miller.
Henry Morley Miller, Stud. Inst. C.E.
Robert Faulds Miller, Stud. Inst. C.E.
George Pilkington Mills, Stud. Inst. C.E.
George Alexander Hutchings Mould.
William Naylor.
Edward Newdigate, Stud. Inst. C.E.
William Barron Norton.
Francis Robert Oke.
George Holt Ormerod.

Associate Members—continued.

Frank Oswell, B.A.
Godfrey Bernard Parlett.
Harold Charles Paxon, A.K.C., Stud. Inst. C.E.
Thomas Perham.
John Edward Sharman Perkins, A.K.C.
Thomas Pope, Jun., Stud. Inst. C.E.
Bertram Edward de Noual Ramus, B.A.
Herbert Byrom Ransom, Stud. Inst. C.E.
Kekobad Hormasjee Rao.
John Charles Dodgson Raper.
Manackji Ratanji, L.C.E.
Andrew Reid.
Samuel Reid.
Peter Felix Richards.
Charles Hay Rivers.
John Broad Roberts.
John Marris Roberts, B.E., Stud. Inst. C.E.
Ernest George Robinson.
John William Brown Rooke.
William Windham Sadler.
Charles Steuart Bell Sanderson, Stud. Inst. C.E.
Cecil Graham Scott, Stud. Inst. C.E.
Thomas Clive Sheppard.
John Smart Sinclair.
Harry Ross Skinner, Stud. Inst. C.E.
Frederick William Slaughter.
Henry Edward Stilgoe, Stud. Inst. C.E.
John Henry Strachan.
Frank Sumner.
Charles Frederick Sykes, F.C.H.
Hugh Pollock Tooker, B.E.
Charles Brandon Trye, Stud. Inst. C.E.
John Morrison Tuckwell.
Andrea Vassallo.
Arthur William Ward.
Charles Edward Waring.
Henry Webster, B.E.
William Herbert Wheeler, B.A., Stud. Inst. C.E.
Henry Gilbert Whyatt.
Arthur Edward Williams.
Charles Louis Napoleon Wilson.

Associates.

John Ebenezer Bousfield.
William Martin, B.A., Wh.Sc.
George Kenneth Scott-Moncrieff, Capt. R.E.

The discussion upon the Paper on "The Manufacture of Small Arms" occupied the evening.

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13 and 20 December, 1892.

HARRISON HAYTER, President,
in the Chair.

The Discussion upon the Paper on "The Manufacture of Small Arms" occupied both evenings.

Sect. II.—OTHER SELECTED PAPERS.

(*Paper No. 2648.*)

"The Signalling at the Waterloo Terminus of the London and South-Western Railway."[1]

By Alfred Weeks Szlumper, M. Inst. C.E.

Historical.

Previous to the year 1867 all the points in Waterloo Yard were worked by hand-levers, and the signals consisted of one disk-signal fixed near the end of the platforms, for indicating to the man working the stop-signal whether a train could be received, a stop-signal, fixed near Westminster Road bridge, and a distant-signal about 400 yards away, towards Vauxhall. The first two signals were worked by hand-levers, and the distant-signal by a lever fixed near the stop-signal. All trains were stopped just outside the station, the engine was shunted, and the train roped in to the platform road; a lever fixed near Westminster Road bridge actuated a gong near the end of the platforms, the number of beats indicating the train that was about to be roped in. This, practically, was the signalling of Waterloo Yard in its earlier days, when the daily average of passenger-trains had reached about 228. This number has now grown to about 570 on a busy day.

In March 1867 a new signal-box, built by Messrs. Stevens & Sons, was opened, and designated the "A" box; it was fitted with a 47-lever locking-frame, in two rows (parallel to the line of railway), 24 referring to the main-line movements and 23 to the Windsor line. A stirrup-frame, for pulling off 4 main and 4 Windsor line signals, was also provided. All the chief points and signals were connected to this box and properly interlocked. In the year 1874 the box was reconstructed, a new one being built alongside in which a 109-lever frame in one length (at right-angles to the line of railway) was fixed by Messrs. Saxby & Farmer, the old box was removed, and all points and signals

[1] Reference may also be made to an article entitled "The New Signalling System and Alterations at Waterloo Station," which appeared in *Engineering* of the 27th May, 24th June, 16th September, and 28th October, 1892.—Sec. Inst. C.E.

were connected with the new one. In the year 1878 another new signal-box was built encasing the 1874 box, so as to enlarge it, the shell of the old box was removed, and an additional row of 35 levers was added by Messrs. Stevens & Sons, parallel to and interlocking with the 109 levers already existing. In 1880, 20 levers were added, followed by 65 more in 1885, bringing up the total to 209 levers in two parallel rows. This signal-box sufficed to work the traffic until the completion of the extensive widening and improvement works,[1] when it became necessary to remodel all the lines leading into the platform bays. As it was not possible to add more levers to the old box, it was decided to build a new one immediately adjacent to it and to complete this new box, with new signals, &c., before disturbing the old one. This new box has been finished and brought into use, and is designated the new "A" box.

New "A" Box.

The signal-box is built on girders spanning the Windsor lines with a gangway 12 feet wide, continued and spanning the main lines to carry some of the rodding, signal-wires, &c. (Plate 1). The box is built in two storeys, the lower floor, 74 feet by 30 feet, containing all the locking-machinery, &c.; and the upper floor is divided in four rooms, viz., a room 60 feet by 30 feet, containing the levers, instruments, &c.; a mess-room, 13 feet 4 inches by 9 feet 6 inches; a battery-room (lined with lead), 15 feet by 9 feet 4 inches; and a telephone-room, 4 feet square—the difference in level between the two floors being 9 feet 5 inches. The upper floor is specially designed to give ready access to any part of the locking-troughs by movable hatches. Practically, the whole of the points, facing-point locks and signals to and from the 18 platform-bays and sidings are worked from this box—the 3 small yard-boxes only working the "in" platform indicating-arms.

Interlocking-Mechanism.

The new box contains an interlocking apparatus of 236 levers, and was made by Messrs. Stevens & Sons, and fitted up in position by that firm. There are 102 signal-levers, working 247 connections; 50 point-levers, working 81 points; 46 facing-point lock-levers, locking 68 points; 7 gear levers, for adjusting the triple working; 16 small setting-levers and 15 spare levers, all

[1] Minutes of Proceedings Inst. C.E., vol. cvii. p. 287.

interlocked for and actually accomplishing the work of 350 levers (Plate 1 and Appendixes). The levers are 8 feet in length, fixed in two parallel rows 12 feet 8 inches apart when in their normal position. The levers are $4\frac{1}{2}$ inches from centre to centre throughout, excepting two spaces of 2 feet 6 inches, one in each row, to afford the signal-men more ready access to the windows of the box, and at the same time to divide the Windsor from the main-line levers. The levers are worked by the signal-men standing between the rows. The interlocking is accomplished in three wide cast-iron horizontal locking-troughs, running from end to end of the apparatus—one in the centre between the rows of levers, containing 51 channels or grooves in which the interlocking mechanism is placed, and one on each side, between the levers and the windows to the box, containing 80 channels. Two long tappets only are used, attached one on each side of each lever, connected by links imparting a horizontal movement to the tappets, which are provided with the necessary bevel-notches &c., to give motion to the locks and slides running in the grooves of the locking-trough at right-angles to the tappets. All the necessary facing- and trailing-points, and also the facing-point locks have to be set before a passenger-train signal can be lowered; in addition to this, special "rotation-locking" is provided for each route, locking the route after the signal has been replaced to "danger" until a particular facing-point lock-lever has been returned to its normal position (generally the central point lock of the route set); the act of returning this lever removes all the back locks. For instance, take Road 7 to A, passenger out (Plate 1 and Appendix I)—gear-lever 128 would be set to the first position; the signal-man would then pull the following levers, viz., points 61 and 59, facing-point locks 64, 63, and 60, and signal 121; this signal-lever would be the first to be replaced, and, although replaced, all the other levers would still remain back-locked until facing-point lock 60 had been put back to its normal position; when the signal-man would be able to replace the remaining levers in the usual manner. This "rotation locking" is an invention of Mr. O'Donnell, and Fig. 1, Plate 2, explains its working (the ordinary releasing of signal 121 by the points, and the other locks are omitted in the Fig.).

Simplex Apparatus.

72 levers have their interlocking-mechanism so arranged that (conditionally upon the position of a gear-lever) each is capable of working three distinct signal-connections; this is accomplished

by the "Simplex" machines, Figs. 2, Plate 2. This "Simplex" apparatus is gathered into nests, or batteries, and there are seven such, fixed at suitable spots under the locking-frame in the lower floor, viz.:—

No. 1. Battery containing the apparatus for levers 7 to 18, controlled by gear-lever No. 19; these 12 levers working 30 signal-connections relating to the up-Windsor line: No. 2. Battery for levers 188 to 199, controlled by gear-lever No. 200; working 30 signal-connections relating to the down-Windsor through line: No. 3. Battery for levers 202 to 216, controlled by gear-lever No. 217; working 39 signal-connections relating to the down-Windsor local line: No. 4. Battery for levers 83 to 95, controlled by gear-lever No. 96; working 36 signal-connections relating to the up main through line: No. 5. Battery for levers 97 to 106, controlled by gear-lever No. 107; working 28 signal-connections relating to the up main local line: No. 6. Battery for levers 121 to 127, controlled by gear-lever No. 128; working 16 signal-connections relating to the down main line: No. 7. Battery for levers 177 to 179, controlled by gear-lever No. 180; working 6 signal-connections relating to the Windsor line engine-table roads. These batteries are not worked up to their full power; No. 1 being capable of working 6, No. 2, 6, No. 3, 6, No. 4, 3, No. 5, 2, No. 6, 5, and No. 7, 3, additional connections. Fig. 2 shows battery No. 1, which is similar in construction to the others. Each battery is fitted up in two tiers, to economise space, and works in a cast-iron guide. A is a blade actuated by the rod-connection F, leading from the tail of the gear-lever. B B^1 are rods leading to the signal-levers and terminating in selector-blades C C^1, which engage with blades D D^1 connecting with the signal-wires. The blade A is provided with a series of studs, or projections, on the upper and lower sides, the selector-blades C C^1 travelling across the path of these studs; the movement of A causing the selector to engage with either one of three blades D in the top row, or one of three blades D^1 in the bottom row, by a stud on the selector fitting in a notch in the blades D D^1. These blades are in fixed bearings, having a movement at right-angles to the blade A. In the first position of A, the selector is engaged with the blades leading to the passenger-train signals; in the second position, A has travelled 2 inches, and the selector now engages with the blades leading to the "out" shunt-signals; and in the third position, A has travelled another 2 inches, when the selector engages with the blades leading to the "in" shunt-signals. Thus in all cases, the first position works the passenger-train con-

nections, the second position, the "out" shunt-connections, and the third position, the "in" shunt-connections. The movements of the gear-levers are properly interlocked, so that it is not possible to set them for a wrong road. Special three-position release-labels and name-plate, and triple electric repeaters, are provided to suit this complex working. By the adoption of this triple working, the locking-apparatus is much reduced in size, and the distance the signal-men have to move about is also less; but the number of pulls is not reduced—the only difference being that the same lever is pulled for 3 distinct signals, instead of a separate lever for each. The 16 small setting-levers are placed between the ordinary levers, and are for interlocking only where alternative routes to the same platform-bay are provided.

Signals.

Fixed on the station side of the new box is a 67-arm iron gallery-signal resting on the girders carrying the box (Plate 1). A signal-bridge spanning all the lines west of Westminster Road bridge carries a 21-arm iron gallery-signal, and at the end of each platform there are iron bracket-signals.

The 67-arm signal consists of two top arms, viz., down-Windsor through and down-Windsor local indicating arms, working in connection with the row of Windsor-line signals, informing the engine-driver which of the two down-Windsor lines the lower signal is given for; the upper row has 20 arms referring to the main lines, and the lower row 27 arms referring to the Windsor line passenger-train movements to and from the 18 platform bays and the 6 running lines, A, B, C, D, E, and F. The lowest row has twelve arms referring to shunting movements, these 12 arms being repeated on the opposite side of the signal-box, and partially so on Westminster Road signal-bridge. The 21-arm signal on this signal-bridge has 6 stop-arms, two for each of three up-roads, B, C, and F; the upper row for the main-line bays 1 to 7, and the lower row for the Windsor-line bays 8 to 18. There are also 6 "in" shunting-arms, one for each road, and 9 arms referring to the down traffic, viz., 6 advance-signals (3 for right and 3 for wrong road), and three distant-signals (the latter worked from the "B" signal-box). Each of the bracket-signals at the end of the platform-bays has passenger-train "starting," shunt "out" on right road, and shunt "out" on wrong road; the latter being indicated by

a scissors-shaped semaphore, ⋈, with a distinctive light (purple) at night. This scissors-arm is a great improvement upon the old arrangement, as the same arm was then used for a "right away" and shunt to "wrong" road signal, a distinctive letter only being lowered over the arm for the latter; this was found unsatisfactory and liable to be mistaken. There is also an arm for arrival traffic, indicating by three positions whether the bay about to be entered has a train already standing in it or is empty (each bay being large enough to take two trains). The working of these signals is described in the section, "Electric Locking to Platform-bays." All these signals are electrically repeated in the "A" box.

Traffic-Movements.

Referring to Plate 1, which presents a diagram of Waterloo yard in its normal state, the lines marked A, B, C, and (1) to (7) (at the end of the platform-bays) are considered as main-line territory, and those marked D, E, F, and (8) to (18) as Windsor-line territory, and these lines are so arranged as to admit of the following traffic-movements, namely:—from the down main line marked A to platform-bays (1) to (7) inclusive, also the Necropolis sidings and main-line turntable and sidings; between the up main local line marked B and platform-bays (1) to (10) inclusive, sidings and main-line turntable; between the up main through line marked C and platform-bays (1) to (13) inclusive, siding and main-line turntable; between the down Windsor local line marked D and platform-bays (4) to (18) inclusive, sidings and Windsor-line turntable; between the down Windsor through line marked E and platform-bays (7) to (18) inclusive, sidings and Windsor-line turntable; between the up Windsor line marked F and platform bays (7) to (18) inclusive, sidings and Windsor-line turntable—the three roads, A, D, and E, being the down lines, and the three marked B, C, and F, up lines. All points are fitted with the ordinary point-locks, and, where possible, safety-bars are provided.

Sykes Electric Lock-and-Block.

In place of the ordinary block system, the Sykes electric lock-and-block has been adopted throughout, and specially arranged for terminus working. This system differs essentially from the ordinary block, inasmuch as the electrical working of the absolute

block system is combined with the mechanical working of the outdoor signals controlled by the movement of the trains passing over treadles fixed to the rails, rendering it practically impossible for a wrong signal to be given. For the up-trains, the first "A" box block section extends from the "B" signal-box (a distance of 467 yards towards Vauxhall) to the "A" box, and the second section from this box to the platform-bays. For the down-trains, the first section may be considered to extend from the platform-bays to the advance signals on the Westminster Road signal-bridge (the mechanical locking of the platform-bay signals, and the automatic working of these advance-signals, practically constituting this section); the second section extends to the "B" box.

Electric Lock-and-Block Instrument.

The electric lock-and-block instruments in the "A" box, working in connection with the "B" box for all up-trains, are shown in Figs. 3 and 4, Plate 2. A represents four 7-inch permanent magnets (capable of supporting about 7 lbs. each); B, a pair of small electromagnets fixed to the poles of the permanent magnets; C, an armature connecting with a stop on F; F F^1 F^2 are lock-blades (labels or tablets are fixed on these blades); E E^1, line springs; G, a small lever connecting with a cross-head on to F and F^2; and H, a rod leading to and actuating the auxiliary lock in the tappet (Figs. 6 and 7). In its normal state the armature is not attracted to the magnet. The man in charge of "A" box having received from "B" box a bell-signal warning him that a train is approaching, he pulls over the small lever G; this action raises the blades F and F^2, also the rod H, putting the lock in the tappet (Fig. 7); it also pushes the armature against the magnet, which is now sustained by magnetic attraction, and the instrument is in a condition to be plunged. This is done and contact is made with the springs E E^1, completing a circuit to the "B" box instrument, and enabling "B" box to release the lever feeding this particular road. At the same time, a click on blade F is pushed aside, when it drops and locks the plunger. A "train on" having been accepted from the "B" box, the switch S is placed over the plunger, breaking the circuit and causing the indicating arm over the "B" box instrument to show "danger." The instrument in "A" box is now locked and remains so until the train passes over a mercurial contact-treadle fixed to the rails near the "in" signal on the signal-bridge; when a circuit is completed with the instrument, causing an opposing current to travel through

the magnets which neutralizes their attractive power, when the armature falls away, releasing the stop on F and allowing the rods F F^2 to drop; these actuate H, pushing it down and removing the lock in the tappet. The instrument now returns to its normal position. This instrument is a "double," or "sending and receiving" instrument.

The instrument used for down-trains working is somewhat similar to the one described, except that there is no plunger or switch, but only the locking portion, and it is a "single," or "receiving," instrument.

Auxiliary Locks on Signal Levers.

In connection with the Sykes locking, the signal-levers are fitted with auxiliary locks. The signal-levers actuating signals relating to trains approaching Waterloo are provided with a direct-acting electric lock, Figs. 5, Plate 2. A is an electro-magnet, B is an armature actuating the lock C, D is a tappet fixed to the lever, having a notch at E; F F^1 are insulated springs, and G is an ebonite pin. The lock is normally in the notch in the tappet that locks the lever. When a circuit is made with one of the yard boxes, the magnet A attracts the armature, lifting the lock from the notch, when the signal-lever is released. These electric locks are disconnected for an "in" or "out" shunt movement—the action of setting the gear lever accomplishing this by lowering the tappet D free of the lock C.

The auxiliary locks fitted to the signal-levers that actuate the "advance" signals is a double lock, Fig. 6; A is the lock hung on a mount G; B is a tappet fixed to the lever; C C^1 are notches in the tappet; D is a rod connecting with the lock-and-block instrument; D^1 is a rod tailed into a mechanical locking instrument, (G^1, Fig. 8); E is a shifting cam. In the operation of pulling over the lever, the cam E engages with the rod D, raising it; this locks the lock-and-block instrument, and also actuates the lock A, which now drops into the rear notch in the tappet. The lever thus becomes locked, and remains so until the train passes over a mercurial contact-treadle (close to the advance signal), completing a circuit with the lock-and-block instrument, releasing the rod D (H, Fig. 3); this drops down, and the lock is raised from the tappet. The lever is now returned home, and the cam E, in the return motion, again raises D, locks the instrument, and causes the lock A to drop into the front notch; the lever is now again locked, and cannot be used until a circuit between the "B Box" and

"A Box" is made; this is effected when the train reaches the former box. When the lever is pulled over, D^1 is pushed upwards, and this locks the group of starting-signals by means of the mechanical locking-instrument.

The lock on the starting-signal levers is very similar to the last described, excepting that there is only the front notch in the tappet, and the rod D is tailed into the mechanical-locking instrument (G, Fig. 8). F is a cross-head connecting a group of starting-signal locks. The lever does not become locked until it has been pulled and returned home, when the lock drops into the notch in the tappet by the action of the cam. This lock is removed after the advance-signal has been used, by means of the mechanical-locking instrument, Figs. 8. The auxiliary lock used on the "shunting" signal-levers is shown in Fig. 7. A is the lock hung on a mount at E; B is a tappet fixed to the lever, having a notch C which is under the lock only when the lever is home; D is a rod connecting with the lock-and-block instrument (H, Fig. 3). The lock is normally off, as shown in the Fig., being held in position by the rod D. When the lock-and-block instrument is in use, the lock A, Fig. 7, is placed in the notch locking the lever; and, when the lever is in use, the lock-and-block instrument is locked, as the rod D cannot be moved; consequently, when any shunting operations on the "up" or wrong road, are in hand, it is not possible for "A" box to accept a train from "B" box on this particular road.

All these auxiliary locks are entirely independent of, and in addition to, the ordinary locking.

Mechanical Locking of Group of Platform-Bay "out" Signals.

The cross-head F, Fig. 6, Plate 2, is connected to D, which passes into a mechanical-locking instrument G, Fig. 8, to which is attached a locking-piece A; another rod D^1, Fig. 6, connected with the "advance"-signal lever (relating to this particular group of "out" signals) also enters this instrument, G^1, Fig. 8, terminating in a releaser C; B is a click, D a weight.

When a starting-signal is lowered, A travels upwards, as shown in Fig. 8, "2nd position," and is held in position by the click B; when the "advance"-signal is lowered, G^1 travels towards A, pushing B aside and locking A by the releaser C, Fig. 8; "3rd position," the group of starting-signals are locked until the "advance"-signal is returned to danger, when G^1 is withdrawn, allowing A to drop back to its normal position.

Supposing a "starting"-signal has been lowered, and it is required to return it to "danger" before the train leaves the platform-bay—this is accomplished by inserting a key at F, which actuates E, pushing back the click and allowing A to return; this, of course, would only be used in case of emergency, and before the "advance"-signal has been lowered.

Automatic Working of Advance-Signals.

The down "advance" signals on Westminster Road signal bridge are fitted with "electric reversers," which throw the arms to "danger" immediately a train passes. This automatic working of the "advance" signals is of great advantage, as a down train actually protects its own rear; moreover, many of the trains leaving Waterloo are followed by light engines; these are brought up at the "advance" signals.

Electric Reverser.

The electric reversers are fixed to the signal-rods, and when the signal is lowered, a pin P, Fig. 9, Plate 2, projecting from the back of the reverser, comes into contact with an insulated spring fitted to the signal-post, through which a circuit is carried to a mercurial contact-treadle, Figs. 14, fixed to the rails near the signal. A A are a pair of electro-magnets; B is an armature actuating the link and cross-bar C; D is a hammer fitted with the stop E which is locked by C; F is a pin connecting with the lock G which holds a link H in position. Directly a train passes by the treadle, a circuit is completed to the reverser, exciting the magnets which then attract the armature B, releasing the stop E and allowing the hammer D to fall and strike the pin F, releasing the lock G. The weight of the reverser now causes it to drop, and in so doing it puts the signal to "danger." As the reverser drops, the rod J pushes H aside, and a cam K engages with a wheel L fixed to the hammer, raising the latter and re-setting it. When the signal-man returns the signal-lever home, J is withdrawn to its normal position and the reverser is re-set. The "advance" and "distant" signals being slotted, the reverser actuates both at the same time.

Dual Working of "In" Signals (Shunting).

The "in" shunting-signals on the signal-bridge work simultaneously with the "in" shunting-signals on the "A" box, but the signal on the box can be lowered, keeping the one on the bridge to "danger." The dual working of these signals has this advantage—that, if a light engine has been shunted out towards the signal-bridge, "A" box can lower the "in" signal above the box, keeping the one on the signal-bridge to "danger." The engine now shunts back, and is protected during its shunting movements by the signal on the signal-bridge; whilst another train can be brought up to the signal-bridge from the "B" box, entering the yard directly the shunting movements of the light engine are completed.

Electric Selector.

This dual working is accomplished by an electric selector, which is fixed to the signal-rod connecting the two signals, Fig. 10, Plate 8. A is an electro-magnet; B is the armature, connected with and actuating C; DD′ is the signal-rod joining the arm on the signal-bridge with the corresponding arm on the "A" box. In its normal state the selector is inactive, and the rod DD′ is practically continuous, carrying the selector with it as it moves. Should the signal-man wish to bring the selector into use, he switches on a current, and the electro-magnet A attracts the armature, displacing C from the line of the signal-rod, so that when D travels D′ remains inactive. The signal in the rear of the selector (on the "A" box) can now be lowered, that on the signal-bridge remaining at "danger."

Electric Locking of Platform-Bays.

The platform "in" signals are worked from the small yard-boxes, the position of the arms being electrically controlled by contact-treadles fixed to one of the rails. Four such treadles are placed in each platform-bay (Figs. 1, 12 and 13, Plate 8). No. 1 treadle may be termed a "danger-bar," and Nos. 2, 3 and 4, "contact treadles." There is a circuit connecting the "danger"-bar with the levers in the yard-boxes, and, should any vehicle be standing on the bar, it would be depressed and the circuit broken; the electric lock could not under these circumstances be raised from the tappet attached to the lever actuating the "in" signal to this road, and it therefore remains locked. The other

treadles are in circuit with the yard-box and platform "in" signals, passing through an electric controller fixed on the signal-post. Supposing all treadles free, the signal-man, by the action of pulling his trigger, A, Fig. 12, joins circuit with the treadle, causing a current to pass through his magnet and raise the lock from the tappet; the act of pulling the lever over makes contact with a line-circuit to the "A" box (it also lowers the platform "in" signal). The electric lock on the lever in the "A" box can now be released by a current passing through the coil, attracting the armature and lifting the lock—the signalman in this box being then enabled to lower his "in" signal for this particular platform-bay. Should, however, either of the treadles Nos. 2, 3, or 4, be depressed, the circuit with the signal (through the controller) is broken, and, in consequence, the electro-magnet in this controller is inactive, causing a trigger to engage with the signal-rod. A, Fig. 11, is an electro-magnet, B an armature connected to a trigger C fitted with a foot C′. When the circuit is complete, the electro-magnet attracts the armature, and the foot C′ remains inside the iron case containing the controller; the signal-rod has then a free movement. Should, however, the circuit be broken, the electro-magnet ceases to attract the armature, and, the trigger C falling away, projects the foot C′, engaging with the spur D on the signal-rod E, which can now only travel far enough to lower the signal to "caution."

Double Contact—Mercurial Treadles.

The contact-treadles fixed to the rails in the platform-bays are very simple in construction (Fig. 13, Plate 8). The flange of a wheel depresses a bar which breaks contact by raising a spring; but these treadles are only suitable where trains pass over slowly; for situations where trains run at high speeds, mercurial contact-treadles, Fig. 14, are used. The treadles are 6 feet in length, and are bolted to the web of one of the rails of a running-road. AA′ are levers 18 inches in length, mounted on pins BB′; C is a pin fixed rigidly to the web of the rail and passing in freely through the treadle-box; DD′ is a small iron vessel containing about a thimbleful of mercury at the end D′ and solid at D; EE′ are platinum points fixed in the vessel, E insulated and attached to a line-wire carried to the signal-box (and also to the electric reversers in the case of the "advance" signals); E′ is connected to earth. When a train passes the treadles, the deflection of the rail causes the pin C to press on the levers AA′; these levers then tilt the mercurial

vessel, when the mercury covers the platinum points, completing a circuit. There are two mercurial vessels to each treadle in case one fails to act.

Crossing Trains at "B" Box.

The "B" signal-box may be considered as the commencement of Waterloo Yard, and as there are at this box compound crossings laid in the running-lines, by which a shunt can be made from and to any line, many crossing-movements from Windsor to main lines, or *vice versâ*, can be more readily carried out at times than at the "A" box; and, to meet this work, by a simple contrivance the movements are electrically controlled from the "A" box. There are fixed in the "B" box two large dial-indicators, and, in the "A" box, switches controlling the movements of these indicators. Supposing "A" box wishes a train to be crossed at "B" box, it informs "B" by bell-instrument and then turns the switch indicating the crossing; this is repeated on the dial-indicator in "B" box. There are six movements to each switch, viz., on the switch referring to up-trains: up-main through to up-main local and *vice versâ;* up-main through to up-Windsor and *vice versâ;* up-main local to up-Windsor and *vice versâ;* and, on the switch referring to the down-trains: down-main to down-Windsor local and *vice versâ;* down-main to down-Windsor through and *vice versâ;* down-Windsor local to down-Windsor through and *vice versâ*. Any single movement of the switch locks the remainder.

Movement of Trains Approaching and Leaving Waterloo.

To more clearly illustrate the signalling and electric locking and blocking, the movements of an up Windsor-line train approaching and entering Waterloo Station and those of a down main-line train leaving the station will now be described. In the first instance, all "up" trains are described from Vauxhall by speaking-instrument to the "A" box. An up Windsor-line train having reached the "B" box section, it is signalled to the "A" box; if accepted, "A" box signal-man pulls the small lever in connection with the lock-and-block instrument, Figs. 3 and 4, Plate 8, locking the "out" shunt-signals feeding this road; he then plunges connecting circuit with the "B" box (see diagram of electrical connections, Fig. 12). This current removes the auxiliary locks from the "B"-box lever feeding this road, and he now pulls his lever and lowers his signals. Directly the train

passes by the mercurial contact-treadle fixed to one of the rails just in advance of "B"-box "advance"-signal, the circuit is broken (it will be noticed that this treadle "breaks" instead of "making" contact by reversing the position of the vessels containing the mercury), and the battery-power given to "B" box by "A" box is destroyed; "B" cannot now send another train on this road until "A" gives him another permit. When the train reaches the mercurial contact-treadle fixed to the rail near the "A"-box "in" signal (on the signal-bridge), a circuit to the "A" box through the "in" signal is completed, re-setting the instrument in this box. The "A" box signal-man will have obtained from the yard-box permission to lower his "stop-"signal (this signal works in rotation with the "in" platform-signal), and the train now enters a platform-bay.

For a down main-line train leaving Waterloo, the platform departure-signal is first lowered from "A" box. The signal-man will have signalled the train on to "B" box, and, if accepted, "B" plunges and releases the lock of the advance-signal on Westminster Road signal-bridge. The act of lowering the platform departure-signal locks all platform-signals leading to this road. The signal-man at "A" box now lowers the "advance" signal, and, in doing so, switches his electric-locking instrument on to the mercurial contact-treadle near this "advance" signal; as soon as the train reaches this treadle, the "advance" signal is automatically put to danger, and it cannot be again lowered until the train reaches a treadle near "B" box, which completes a circuit to "B" box and removes the lock from his instrument.

Electric Buzzer.

When passing the treadle near the "advance" signal, two currents of electricity are set up, one throwing the semaphore to danger, the other completing a circuit to the "A" box, which removes the back lock from the "advance"-signal lever, and, by completing a circuit between the mechanical and electric locking-instruments, actuates a "buzzer," which emits a sound somewhat similar to that of a toy trumpet—continuing until the signal-man restores his lever, the signal being already put to "danger" by the action of the treadle. This "buzzer" always sounds when the mechanical and electric locking-instruments are at variance, the sound being produced by a make-and-break contact on a thin disk of metal. The "buzzer" is simply to remind the signal-man that he has not worked his lever. In the first case it sounds directly

"B" box removes the lock out of the "advance" signal, and continues until "A" box pulls the lever and lowers the signal.

Shunting Out on "Wrong" Road.

For shunting out on the "up" or "wrong" road, the movements are electrically controlled by "B" box; and, before permission is given to "A" box for such a shunt movement, the signal-man at "B" box puts a lock into his up "stop" signals feeding the particular road on which the shunt-movement is about to be carried out. The limit of shunting out on the wrong road extends to a point near "B" box, where ground disks of scissors-pattern are fitted (Plate 7).

Number of Circuits, etc.

The total number of circuits entering the new box is about 250; all the wires are carried underground, and all circuits and wires have been run to disconnecting-boards in the battery-room, so as to be more easy of access. The instruments used have been constructed so as to permit as far as possible the use of the Leclanché type of battery. The number of cells in the boxes and about the yard is about 683, the greater number being for repeating-signals and bells.

Rodding.

The rodding is of necessity very extensive, and, for want of space, is somewhat complex—double-tier rollers having to be resorted to, and rocking-shafts employed for leading away both in "A" box and on the ground. Annett and Wilmer's point-rods, and Stevens & Sons' travelling-rollers are used. In all cases the signal-wires are carried overhead.

Transferring Connections from Old to New Box.

The work of transferring all the connections from the old to the new box was one of considerable magnitude, bearing in mind the large traffic that had to be dealt with at the same time. When the new box was completed, the locking tested and approved by the Board of Trade inspector, and the new points and crossings laid as far as possible, the work of transferring the connections was undertaken; and on the 1st of May, 1892, all the main-line connections were removed from the old signal-box and connected

to the new one. A fortnight then elapsed, during which period preparations were made for the final move. During this fortnight, the main-line traffic was worked from the new box and the Windsor-line traffic from the old one; the shunting from the main line to the Windsor line and *vice versâ* being worked by a temporary ground-frame electrically controlled by both the signal-boxes. On Sunday, the 15th of May, the final move was made—all Windsor-line connections being removed from the old box and connected to the new one; the work of dismantling the former and removing the old signals was now carried on day and night. Meanwhile, the work of laying the new points and crossings proceeded; but a few of these could not be completed until the stanchions supporting the girders which carried the old box were removed. The girders were taken down during the week, and on the following Sunday (the 22nd of May) the stanchions were removed and the remaining points and crossings completed. For the first three days after the final move, it was necessary to discontinue a few local trains, and extra ground-signal-men were stationed in the yard to assist the traffic movements. The completed scheme has now been in use for some months, during which period a heavy traffic has been dealt with (as many as 879 trains, empties, &c., on Saturday, the 16th of July,[1] and on several occasions the number has exceeded 800 per day). This has been done with safety and expedition, the new arrangements working most satisfactorily, being well adapted to deal with the traffic of this, probably the most extensive station in existence.

The communication is accompanied by a series of tracings, from which Plates 7 and 8 have been compiled; also by various photographic and printed documents which may be seen at the Institution.

[1]

	Down Main.	Up Main.	Down Windsor.	Up Windsor.
Trains	118	128	132	127
Engines	40	53	30	27
Empties	21	50	63	22
Special trains . .	23	30	8	7
	202	261	233	183

Grand Total = 879.

APPENDIXES.

NOTE.—Figures marked (*61*) are point-levers that are not back-locked by the signal.

The first, second and third positions of the gear lever are indicated thus: 124^{I}, 124^{II}, 124^{III}.

Figures marked thus, 126^{II}, are the "A" or "B" position of the setting-levers.

APPENDIX I.

"A" BOX INTERLOCKING.—DOWN-MAIN LINE "A." PULLS.

Road.	Traffic Movement.	Pull Lever.
"A" to Necropolis.	Passenger in . . .	117, 138.
Necropolis to "A".	Passenger out . . .	117, 139.
"A" to siding . .	Fly shunt in . . .	118, (*115*), 127^{III}.
Siding to "A" .	Shunt out	118, (*115*), 138, 110.
"A" to Road 1 .	Fly shunt in . . .	118, 127^{III}.
Road 1 to "A" .	Passenger out . . .	118, 112, 138, 127^{I}.
Road 1 to "A". .	Shunt out	118, 138, 127^{II}.
"A" to Road 2 .	Over 118, fly shunt in	(*113*), 118, 127^{III}.
"A" to Road 2 .	Over 109, fly shunt in	131, (*109*), 125^{III}.
Road 2 to "A"	Over 118, passenger out	118, 113, 112, 132, 138, 126^{BI}.
Road 2 to "A". .	Over 109, passenger out	131, 109, 60, 132, 126^{AI}.
Road 2 to "A". .	Over 118, shunt out .	118, 113, 138, 126^{BII}.
Road 2 to "A". .	Over 109, shunt out .	131, 109, 126^{AII}.
"A" to table . .	Over 118, fly shunt in	(*113*), (*111*), 118, 127^{III}.
"A" to table . .	Over 56, fly shunt in .	(*56*), 125^{III}.
Out of table . . .	Over 111, shunt out .	113, 111, 129.
Table to "A" . .	Over 56, shunt out .	56, 142.
"A" to Road 3 .	Straight, fly shunt in.	125^{III}.
Road 3 to "A". .	Passenger out . . .	60, 125^{I}.
Road 3 to "A". .	Shunt out	125^{II}.
"A" to Road 4 .	Over 62, fly shunt in .	(*62*), 125^{III}.
"A" to Road 4 .	Over 61, fly shunt in .	(*61*), (*52*), 125^{III}.
Road 4 to "A". .	Passenger out . . .	62, 58, 60, 124^{I}.
Road 4 to "A". .	Shunt out	62, 124^{II}.
"A" to Road 5 .	Over 61, fly shunt in .	(*61*), (*53*), 125^{III}.
"A" to Road 5 .	Over 62, fly shunt in .	(*62*), (*57*), (*53*), 125^{III}.
Road 5 to "A". .	Passenger out . . .	62, 57, 53, 67, 60, 123^{I}.
Road 5 to "A". .	Shunt out	62, 57, 53, 123^{II}.
"A" to Road 6 .	Over 61, fly shunt in .	(*61*), 125^{III}.
"A" to Road 6 .	Over 62, fly shunt in .	(*62*), (*57*), 125^{III}.
Road 6 to "A". .	Passenger out . . .	62, 57, 67, 60, 122^{I}.
Road 6 to "A". .	Shunt out . . .	62, 57, 122^{II}.
"A" to Road 7 .	Fly shunt in . . .	(*61*), (*59*), 125^{III}.
Road 7 to "A". .	Passenger out . . .	61, 59, 64, 63, 60, 121^{I}.
Road 7 to "A". .	Shunt out	61, 59, 121^{II}.

APPENDIX II.

"A" Box Interlocking.—Up-Main Local Line "B." Pulls.

Road.	Traffic Movement.	Pull Lever.
"B" to siding . .	Fly shunt in . . .	(*115*), 81, 116, 106III.
Siding to "B" . .	Shunt out	115, 81, 116, 135, 136, 82.
"B" to Road 1 .	Fly shunt in . . .	116, 81, 106III.
"B" to Road 1 .	Passenger in . . .	116, 81, 114, 80, 78, 112, 106I, 119.
Road 1 to "B" .	Shunt out	116, 81, 135, 136, 106II.
"B" to Road 2 .	Over 81, fly shunt in .	116, 81, (*113*), 106III.
"B" to Road 2 .	Over 109, fly shunt in	116, 131, (*109*), 104III.
"B" to Road 2 .	Over 81, passenger in	113, 81, 116, 130, 80, 78, 112, 105BI, 119.
"Road 2 to "B" .	Over 81, shunt out .	113, 81, 116, 135, 136, 105BII.
"B" to Road 2 . .	Over 109, passenger in	131, 109, 116, 108, 66, 80, 78, 60, 105AI, 119.
Road 2 to "B" . .	Over 109, shunt out .	131, 109, 116, 135, 136, 105AII.
"B" to table . .	Over 111, fly shunt in	116, 81, (*113*), (*111*), 106III.
"B" to table . .	Over 56, fly shunt in .	116, (*56*), 104III.
Table to "B" . .	Over 56, shunt out .	116, 56, 135, 136, 141.
"B" to Road 3 . .	Fly shunt in . . .	116, 104III.
"B" to Road 3 . .	Passenger in . . .	116, 108, 66, 80, 78, 60, 104I, 119.
Road 3 to "B" . .	Shunt out	116, 135, 136, 104II.
"B" to Road 4 . .	Fly shunt in . . .	103BIII.
"B" to Road 4 . .	Over 116, fly shunt in	116, (*62*), 104III, or 116 (*61*), (*52*), 104III.
"B" to Road 4 . .	Straight, passenger in	78, 65, 103BI, 119.
"B" to Road 4 . .	Over 55, passenger in	52, 70, 55, 51, 68, 65, 78, 54, 103AI, 119.
Road 4 to "B" . .	Straight, shunt out .	135, 136, 103BII.
Road 4 to "B" . .	Over 55, shunt out .	52, 70, 55, 135, 136, 103AII.
"B" to Road 5 . .	Over 116, fly shunt in	116, (*61*), (*53*), 104III, or 116, (*62*), (*57*), (*53*), 104III.
"B" to Road 5 . .	Fly shunt in . . .	(*55*), (*70*), (*53*), 103BIII.
"B" to Road 5 . .	Passenger in . . .	53, 55, 70, 51, 68, 65, 78, 54, 102I, 119.
Road 5 to "B" . .	Shunt out	53, 55, 70, 135, 136, 102II.
"B" to Road 6 . .	Fly shunt in . . .	55, 70, 103BIII.
"B" to Road 6 . .	Over 116, fly shunt in	116, (*61*), 104III, or 116, (*62*), (*57*), 104III.
"B" to Road 6 . .	Passenger in . . .	55, 70, 51, 68, 65, 78, 54, 101I, 119.
Road 6 to "B" . .	Shunt out	55, 70, 135, 136, 101II.
"B" to Road 7 . .	Fly shunt in . . .	(*55*), 103BIII.
"B" to Road 7 . .	Over 116, fly shunt in	116, (*61*), (*59*), 104III.
"B" to Road 7 . .	Passenger in . . .	55, 68, 65, 78, 54, 100I, 119.
Road 7 to "B" . .	Shunt out	55, 135, 136, 100II.
"B" to Road 8 . .	Passenger in . . .	55, 46, 42, 36, 48, 65, 78, 68, 99I, 119.
"B" to Road 8 . .	Shunt in	55, 46, 42, 36, 99III.
Road 8 to "B" . .	Shunt out	55, 46, 42, 36, 135, 136, 99II.
"B" to Road 9 . .	Passenger in . . .	55, 42, 36, 48, 65, 78, 68, 98I, 119.
"B" to Road 9 . .	Shunt in	55, 42, 36, 98III.
Road 9 to "B" . .	Shunt out	55, 42, 36, 135, 136, 98II.
"B" to Road 10 .	Passenger in . . .	55, 45, 42, 36, 48, 65, 78, 68, 97I, 119.
"B" to Road 10 .	Shunt in	55, 45, 42, 36, 97III.
Road 10 to "B" .	Shunt out	55, 45, 42, 36, 135, 136, 97II.

APPENDIX III.

"A" Box Interlocking.—Up-Main Through Line C. Pulls.

Road.	Traffic Movement.	Pull Lever.
"C" to siding	Fly shunt in	81, 76, 79, 77, (*115*), 95^{III}.
Siding to "C"	Shunt out	115, 81, 76, 79, 133, 134, 82.
"C" to Road 1	Passenger in	81, 76, 79, 114, 80, 78, 77, 112, 95^{I}, 120.
"C" to Road 1	Fly shunt in	81, 76, 79, 77, 95^{III}.
Road 1 to "C"	Shunt out	81, 76, 79, 133, 134, 95^{II}.
"C" to Road 2	Over 81, fly shunt in	(*113*), 81, 76, 79, 77, 95^{III}.
"C" to Road 2	Over 109, fly shunt in	131, 109, 116, 76, 79, 77, 93^{III}.
"C" to Road 2	Over 109, passenger in	131, 109, 116, 76, 79, 108, 66, 80, 78, 77, 60, 94^{AI}, 120.
"C" to Road 2	Over 81, passenger in	113, 81, 76, 79, 130, 80, 77, 78, 112, 94^{BI}, 120.
Road 2 to "C"	Over 109, shunt out	131, 109, 116, 76, 79, 133, 134, 94^{AII}.
Road 2 to "C"	Over 81, shunt out	113, 81, 76, 79, 133, 134, 94^{BII}.
"C" to table	Over 81, fly shunt in	81, 76, 79, 77, (*113*), (*111*), 95^{III}.
"C" to table	Over 56, fly shunt in	116, 76, 79, 77, (*56*), 93^{III}.
Table to "C"	Over 56, shunt out	116, 76, 79, 56, 133, 134, 140.
"C" to Road 3	Fly shunt in	116, 76, 79, 77, 93^{III}.
"C" to Road 3	Passenger in	116, 76, 79, 108, 66, 80, 78, 77, 60, 93^{I}, 120.
Road 3 to "C"	Shunt out	116, 76, 79, 133, 134, 93^{II}.
"C" to Road 4	Over 116, fly shunt in	116, 76, 79, 77, (*62*), 93^{III}.
"C" to Road 4	Over 76, fly shunt in	76, 77, 92^{BIII}.
"C" to Road 4	Over 70, fly shunt in	77, (*70*), (*52*), 89^{III}.
"C" to Road 4	Over 70, passenger in	52, 70, 51, 68, 75, 77, 54, 92^{AI}, 120.
"C" to Road 4	Over 76, passenger in	76, 77, 78, 65, 92^{BI}, 120.
Road 4 to "C"	Over 70, shunt out	52, 70, 133, 134, 92^{AII}.
Road 4 to "C"	Over 76, shunt out	76, 133, 134, 92^{BII}.
"C" to Road 5	Over 116, fly shunt in	116, 76, 79, 77, (*61*), (*53*), 93^{III}, or 116, 76, 79, 77, (*62*), (*57*), (*53*), 93^{III}.
"C" to Road 5	Over 76, fly shunt in	76, 77, (*55*), (*70*), (*53*), 92^{BII}.
"C" to Road 5	Over 70, fly shunt in	77, (*70*), (*53*), 89^{III}.
"C" to Road 5	Passenger in	53, 70, 51, 68, 75, 77, 54, 91^{I}, 20.

APPENDIX III.—*continued.*

"A" Box Interlocking.—Up-Main Through Line C—*continued.*

Road.	Traffic Movement	Pull Lever.
Road 5 to "C"	Shunt out	53, 70, 133, 134, 91[II].
"C" to Road 6	Over 116, fly shunt in	116, 76, 79, 77, (*61*), 93[III], or 116, 76, 79, 77, (*62*), (*57*), 93.
"C" to Road 6	Over 76, fly shunt in	76, 77, (*55*), (*70*), 92[BIII].
"C" to Road 6	Over 70, fly shunt in	77, (*70*), 89[III].
"C" to Road 6	Passenger in	70, 51, 68, 75, 77, 54, 90[I], 120.
Road 6 to "C"	Shunt out	70, 133, 134, 90.
"C" to Road 7	Over 116, fly shunt in	116, 76, 79, 77, (*61*), (*59*), 93[III].
"C" to Road 7	Over 76, fly shunt in	76, 77, (*55*), 92[BIII].
"C" to Road 7	Straight fly shunt in	77, 89[III].
"C" to Road 7	Passenger in	68, 75, 77, 54, 89[I].
Road 7 to "C"	Shunt out	133, 134, 89[II].
"C" to Road 8	Passenger in	42, 46, 48, 75, 77, 68, 88[I], 120.
"C" to Road 8	Shunt in	42, 46, 77, 88[III].
Road 8 to "C"	Shunt out	42, 46, 133, 134, 88[II].
"C" to Road 9	Passenger in	42, 48, 75, 77, 68, 87[I], 120.
"C" to Road 9	Shunt in	42, 77, 87[III].
Road 9 to "C"	Shunt out	42, 133, 134, 87[II].
"C" to Road 10	Over 73, passenger in	44, 43, 39, 73, 47, 33, 75, 77, 30, 86[AI], 120.
"C" to Road 10	Over 42, passenger in	45, 42, 48, 75, 77, 68, 86[BI], 120.
"C" to Road 10	Over 73, shunt out	44, 43, 39, 73, 133, 134, 86[AII].
"C" to Road 10	Over 42, shunt out	45, 42, 133, 134, 86[BII].
Road 10 to "C"	Over 73, shunt in	44, 43, 39, 73, 77, 86[AIII].
Road 10 to "C"	Over 42, shunt in	45, 42, 77, 86[BIII].
"C" to Road 11	Passenger in	43, 39, 73, 47, 33, 75, 77, 30, 85[I], 120.
"C" to Road 11	Shunt in	43, 39, 73, 77, 85[III].
Road 11 to "C"	Shunt out	43, 39, 73, 133, 134, 85[II].
"C" to Road 12	Passenger in	39, 73, 167, 33, 75, 77, 30, 84[I], 120.
"C" to Road 12	Shunt in	39, 73, 77, 84[III].
Road 12 to "C"	Shunt out	39, 73, 133, 134, 84[II].
"C" to Road 13	Passenger in	166, 39, 73, 167, 33, 75, 77, 30, 83[I], 120.
"C" to Road 13	Shunt in	166, 39, 73, 77, 83[III].
Road 13 to "C"	Shunt out	166, 39, 73, 133, 134, 83[II].

APPENDIX IV.

"A" Box Interlocking.—Down-Windsor Local Line "D." Pulls.

Road.	Traffic Movement.	Pull Lever.
"D" to Road 4	Shunt in	71, 70, 52, 219, 216^{III}.
Road 4 to "D"	Passenger out	71, 70, 52, 69, 64, 67, 58, 218, 72, 216^{I}.
Road 4 to "D"	Shunt out	71, 70, 52, 216^{II}.
"D" to Road 5	Shunt in	71, 70, 53, 219, 215^{III}.
Road 5 to "D"	Passenger out	71, 70, 53, 69, 64, 67, 218, 72, 215^{I}.
Road 5 to "D"	Shunt out	71, 70, 53, 215^{II}.
"D" to Road 6	Shunt in	71, 70, 219, 214^{III}.
Road 6 to "D"	Passenger out	71, 70, 69, 64, 67, 218, 72, 214^{I}.
Road 6 to "D"	Shunt out	71, 70, 214^{II}.
"D" to Road 7	Shunt in	50, 41, 219, 213^{III}.
Road 7 to "D"	Passenger out	50, 41, 34, 63, 218, 35, 213^{I}.
Road 7 to "D"	Shunt out	50, 41, 213^{II}.
"D" to Road 8	Fly shunt in	(*46*), 219, 211^{III}.
Road 8 to "D"	Passenger out	46, 34, 48, 218, 35, 212^{I}.
Road 8 to "D"	Shunt out	46, 212^{II}.
"D" to Road 9	Fly shunt in	219, 211^{III}.
Road 9 to "D"	Passenger out	34, 48, 218, 35, 211^{I}.
Road 9 to "D"	Shunt out	211^{II}.
"D" to Road 10	Over 45, fly shunt in	219, (*45*), 211^{III}.
"D" to Road 10	Over 39, fly shunt in	39, (*43*), (*44*), 219, 207^{BIII}.
Road 10 to "D"	Passenger out	39, 43, 44, 30, 49, 218, 35, 210^{I}.
Road 10 to "D	Shunt out	39, 43, 44, 210^{II}.
"D" to Road 11	Over 39, fly shunt in	39, 219, (*43*), 207^{BIII}.
"D" to Road 11	Over 147, fly shunt in	147, 219, (*155*), 206^{III}.
Road 11 to "D"	Over 147, passenger out	147, 155, 148, 157, 218, 29, 209^{AI}.
Road 11 to "D"	Over 147, shunt out	147, 155, 209^{AII}.
Road 11 to "D"	Over 39, passenger out	39, 43, 30, 157, 218, 35, 209^{BI}.
Road 11 to "D"	Over 39, shunt out	39, 43, 209^{BII}.
"D" to Road 12	Over 39, fly shunt in	39, 219, 207^{BIII}.
"D" to Road 12	Over 147, fly shunt in	147, 219, (*155*), 206^{III}.
"D" to Road 12	Over 147, 31, fly shunt in	147, 31, 219, (*163*), (*160*), 205^{III}.
Road 12 to "D"	Over 147, passenger out	147, 160, 148, 161, 162, 218, 29, 208^{AI}.

APPENDIX IV.—*continued.*

"A" Box Interlocking.—Down-Windsor Local Line "D"—*continued.*

Road.	Traffic Movement.	Pull Lever.
Road 12 to "D"	Over 147, shunt out	147, 160, 208^{AII}.
Road 12 to "D"	Over 39, passenger out	39, 30, 162, 218, 35, 208^{BI}.
Road 12 to "D"	Over 39, shunt out	39, 208^{BII}.
"D" to Road 13	Over 39, fly shunt in	39, 219, (*166*), 207^{BIII}.
"D" to Road 13	Over 147, fly shunt in	147, 219, (*154*), 206^{III}.
" " to Road 13	Over 147, 31, fly shunt in.	147, 31, 219, (*163*), (*154*), 205^{III}.
Road 13 to "D"	Over 147, passenger out	147, 154, 148, 161, 165, 218, 29, 207^{AI}.
Road 13 to "D"	Over 147, shunt out	147, 154, 207^{AII}.
Road 13 to "D"	Over 39, passenger out	39, 166, 30, 165, 218, 35, 207^{BI}.
Road 13 to "D"	Over 39, shunt out	39, 166, 207^{BII}.
"D" to Road 14	Over 147, fly shunt in	147, 219, 206^{III}.
"D" to Road 14	Over 147, 31, fly shunt in	147, 31, 219, (*163*), 205^{III}.
Road 14 to "D"	Passenger out	147, 148, 161, 218, 29, 206 .
Road 14 to "D"	Shunt out	147, 206^{II}.
"D" to Road 15	Fly shunt in	147, 31, 219, 205^{III}.
Road 15 to "D"	Passenger out	147, 31, 148, 146, 218, 29, 205^{I}.
Road 15 to "D"	Shunt out	147, 31, 205^{II}.
"D" to Road 16	Fly shunt in	147, 31, 149, 219, (*168*), 202^{III}.
Road 16 to "D"	Passenger out	147, 31, 149, 168, 148, 146, 218, 29, 204^{I}.
Road 16 to "D"	Shunt out	147, 31, 149, 168, 204^{II}.
"D" to Road 17	Fly shunt in	147, 31, 149, 219, (*170*), 202^{III}.
Road 17 to "D"	Passenger out	147, 31, 149, 170, 148, 146, 218, 29, 203^{I}.
Road 17 to "D"	Shunt out	147, 31, 149, 170, 203^{II}.
"D" to Road 18	Fly shunt in	147, 31, 149, 219, 202^{III}.
Road 18 to "D"	Passenger out	147, 31, 149, 148, 146, 218, 29, 202^{I}.
Road 18 to "D"	Shunt out	147, 31, 149, 202^{II}.
"D" to out Table	Fly shunt in	147, 31, 149, 219, (*158*), (*176*), 202^{III}.
"D" to in Table	Fly shunt in	147, 31, 149, 219, (*158*), (*175*), 176, 202^{III}.
Out Table to "D"	Shunt out	31, 147, 149, 158, 176, 179^{I}.
In Table to "D"	Shunt out	31, 147, 149, 158, 175, 176, 179^{II}.

APPENDIX V.

"A" Box Interlocking.—Down-Windsor Through Line "E." Pulls.

Road.	Traffic Movement.	Pull Lever.
"E" to Road 7.	Shunt in	32, 40, 50, 41, 199III.
Road 7 to "E".	Passenger out . . .	32, 40, 50, 41, 148, 34, 63, 201, 29, 199I.
Road 7 to "E".	Shunt out	32, 40, 50, 41, 199II.
"E" to Road 8.	Fly shunt in . . .	32, 40, 46, 197III.
Road 8 to "E".	Passenger out . . .	32, 40, 46, 148, 34, 48, 201, 29, 198I.
Road 8 to "E".	Shunt out	32, 40, 46, 198II.
"E" to Road 9.	Fly shunt in . . .	32, 40, 197III.
Road 9 to "E".	Passenger out . . .	32, 40, 148, 34, 48, 201, 29, 197I.
Road 9 to "E".	Shunt out	32, 40, 197II.
"E" to Road 10	Fly shunt in . . .	32, (*43*), (*44*), 193BIII.
"E" to Road 10	Over 40, fly shunt in .	32, 40, (*45*), 197III.
Road 10 to "E"	Shunt out	32, (*43*), 44, 196II.
Road 10 to "E"	Passenger out . . .	32, 43, 44, 148, 49, 30, 201, 29, 196I.
"E" to Road 11	Over 155, fly shunt in	(*155*), 192III.
"E" to Road 11	Over 32, fly shunt in .	32, (*43*), 193BIII.
Road 11 to "E"	Over 155, passenger out	155, 148, 157, 201, 29, 195AI.
Road 11 to "E"	Over 155, shunt out .	155, 195AII.
Road 11 to "E"	Over 32, passenger out	32, 43, 148, 30, 157, 201, 29, 195BI.
Road 11 to "E"	Over 32, shunt out .	32, 43, 195BII.
"E" to Road 12	Over 32, fly shunt in .	32, 193BIII.
"E" to Road 12	Over 160, fly shunt in	(*160*), 192III.
"E" to Road 12	Over 31 and 160, fly shunt in	31, (*163*), (*160*), 191III.
Road 12 to "E"	Over 160, passenger out	160, 148, 161, 162, 201, 29, 194AI.
Road 12 to "E"	Over 160, shunt out .	160, 194AII.
Road 12 to "E"	Over 32, passenger out	32, 148, 30, 162, 201, 29, 194BI.
Road 12 to "E"	Over 32, shunt out .	32, 194BII.
"E" to Road 13	Over 32, fly shunt in .	32, (*166*), 193BIII.
"E" to Road 13	Over 154, fly shunt in	(*154*), 192III.

APPENDIX V.—*continued.*

"A" Box Interlocking—Down-Windsor Through Line "E"—*continued.*

Road.	Traffic Movement.	Pull Lever.
"E" to Road 13 .	Over 31 and 154, fly shunt in	31, (*163*), (*154*), 191^{III}.
Road 13 to "E" .	Over 154, passenger out	154, 148, 161, 165, 201, 29, 193^{AI}.
Road 13 to "E" .	Over 154, shunt out .	154, 193^{AII}.
Road 13 to "E" .	Over 32, passenger out	32, 166, 148, 30, 165, 201, 29, 193^{BI}.
Road 13 to "E" .	Over 32, shunt out .	32, 166, 193^{BII}.
"E" to Road 14 .	Straight, fly shunt in .	192^{III}.
"E" to Road 14 .	Over 31, fly shunt in .	31, (*163*), 191^{III}.
Road 14 to "E" .	Straight, passenger out	148, 161, 201, 29, 192^{I}.
Road 14 to "E" .	Straight, shunt out .	192^{II}.
"E" to Road 15 .	Fly shunt in . . .	31, 191^{III}.
Road 15 to "E" .	Passenger out . .	31, 148, 146, 201, 29, 191^{I}.
Road 15 to "E" .	Shunt out	31, 191^{II}.
"E" to Road 16 .	Fly shunt in . . .	31, 149, (*168*), 188^{III}.
Road 16 to "E" .	Passenger out . .	31, 149, (*168*), 148, 146, 201, 29, 190^{I}.
Road 16 to "E" .	Shunt out	31, 149, 168, 190^{II}.
"E" to Road 17 .	Fly shunt in . . .	31, 149, (*170*), 188^{III}.
Road 17 to "E" .	Passenger out . . .	31, 149, 170, 148, 146, 201, 29, 189^{I}.
Road 17 to "E" .	Shunt out	31, 149, 170, 189^{II}.
"E" to Road 18 .	Fly shunt in . . .	31, 149, 188^{III}.
Road 18 to "E" .	Passenger out . . .	31, 149, 148, 146, 201, 29, 188^{I}.
Road 18 to "E" .	Shunt out	31, 149, 188^{II}.
"E" to Table . .	Fly shunt in . . .	31, 149, (*158*), (*175*), (*176*), 188^{III}.
Out Table Road to "E"	Shunt out	31, 149, 158, 176, 178.
In Table Road to "E"	Shunt out	31, 149, 158, 175, 176, 178^{II}.

APPENDIX VI.

"A" Box Interlocking.—Up-Windsor Line "F." Pulls.

Road.	Traffic Movement.	Pull Lever.
"F" to Road 7 . .	Passenger in	38, 28, 40, 50, 41, 33, 27, 37, 34, 18^{I}, 1.
"F" to Road 7 . .	Shunt in	38, 28, 40, 51, 41, 37, 18^{III}.
Road 7 to "F" . .	Shunt out	38, 28, 40, 50, 41, 2, 3, 18^{II}.
"F" to Road 8 . .	Passenger in	38, 28, 40, 46, 48, 33, 27, 37, 34, 17^{I}, 1.
"F" to Road 8 . .	Fly shunt in	38, 28, 40, 37, (*46*), 16^{III}.
Road 8 to "F" . .	Shunt out	38, 28, 40, 46, 2, 3, 17^{II}.
"F" to Road 9 . .	Fly shunt in	38, 28, 40, 37, 16^{III}.
"F" to Road 9 . .	Passenger in	38, 28, 40, 48, 33, 27, 37, 34, 16^{I}, 1.
Road 9 to "F" . .	Shunt out	38, 28, 40, 2, 3, 16^{II}.
"F" to Road 10 .	Over 40, fly shunt in .	38, 28, 40, 37, (*45*), 16^{III}.
"F" to Road 10 .	Over 44, fly shunt in .	38, 28, 37, (*43*), (*44*), 12^{BIII}.
"F" to Road 10 .	Passenger in	44, 43, 38, 28, 47, 33, 27, 37, 30, 15^{I}, 1.
Road 10 to "F" .	Shunt out	44, 43, 38, 28, 2, 3, 15^{II}.
"F" to Road 11 .	Over 28, fly shunt in .	38, 28, 37, (*43*), 12^{BIII}.
"F" to Road 11 .	Over 155, fly shunt in	38, 37, (*155*), 11^{BIII}.
"F" to Road 11 .	Over 155, passenger in	38, 155, 29, 27, 37, 156, 14^{AI}, 1.
"F" to Road 11 .	Over 28, passenger in	38, 28, 43, 47, 33, 27, 37, 37, 30, 14^{BI}, 1.
Road 11 to "F" .	Over 155, shunt out .	38, 155, 2, 3, 14^{AII}.
Road 11 to "F" .	Over 28, shunt out .	38, 28, 43, 2, 3, 14^{BII}.
"F" to Road 12 .	Over 28, fly shunt in .	38, 28, 37, 12^{BIII}.
"F" to Road 12 .	Over 38, 160, fly shunt in.	38, 37, (*160*), 11^{BIII}.
"F" to Road 12 .	Over 152, fly shunt in.	152, 37, (*163*), (*160*), 10^{III}, or 7^{III}.
"F" to Road 12 .	Over 152, passenger in	152, 163, 160, 161, 153, 37, 151, 13^{AI}, 1.
"F" to Road 12 .	Over 28, passenger in	38, 28, 167, 33, 27, 37, 30, 13^{BI}, 1.
Road 12 to "F" .	Over 152, shunt out .	152, 163, 160, 2, 3, 13^{AII}.
Road 12 to "F" .	Over 28, shunt out .	38, 28, 2, 3, 13^{BII}.

APPENDIX VI.—*continued.*

"A" Box Interlocking.—Up-Windsor Line "F"—*continued.*

Road.	Traffic Movement.	Pull Lever.
"F" to Road 13 .	Over 28, fly shunt in .	38, 28, 37 (*166*), 12^{BIII}.
"F" to Road 13 .	Over 38, 154, fly shunt in	38, 37, (*154*), 11^{BIII}.
"F" to Road 13 .	Over 152, fly shunt in	152, 37, 163, 154, 10^{III}, or 7^{III}.
"F" to Road 13 .	Over 152, passenger in	152, 163, 154, 164, 161, 153, 37, 151, 12^{AI}, 1.
"F" to Road 13 .	Over 28, passenger in	38, 28, 166, 167, 33, 27, 37, 30, 12^{BI}, 1.
Road 13 to "F" .	Over 152, shunt out .	152, 163, 154, 2, 3, 12^{AII}.
Road 13 to "F" .	Over 28, shunt out .	38, 28, 166, 2, 3, 12^{BII}.
"F" to Road 14 .	Over 38, fly shunt in .	38, 37, 11^{BIII}.
"F" to Road 14 .	Over 152, fly shunt in	152, 37, (*163*), 10^{III}, or 7^{III}.
"F" to Road 14 .	Over 152, passenger in	152, 163, 164, 161, 153, 37, 151, 11^{AI}, 1.
"F" to Road 14 .	Over 38, passenger in	38, 164, 161, 29, 27, 37, 156, 11^{BI}, 1.
Road 14 to "F" .	Over 38, shunt out .	38, 2, 3, 11^{BII}.
Road 14 to "F" .	Over 152, shunt out .	152, 163, 2, 3, 11^{AII}.
"F" to Road 15 .	Fly shunt in . . .	152, 37, 10^{III}, or 7^{III}.
"F" to Road 15 .	Passenger in . . .	152, 153, 37, 151, 10^{I}, 1.
Road 15 to "F" .	Shunt out	152, 2, 3, 10^{II}.
"F" to Road 16 .	Fly shunt in . . .	37, (*168*), 7^{III}.
"F" to Road 16 .	Passenger in . . .	168, 169, 153, 37, 151, 9_{I}, 1.
Road 16 to "F" .	Shunt out	168, 2, 3, 9^{II}.
"F" to Road 17 .	Fly shunt in . . .	37 (*170*), 7^{III}.
"F" to Road 17 .	Passenger in . . .	170, 171, 169, 153, 37, 151, 8^{I}, 1.
"F" to Road 18 .	Fly shunt in . . .	37, 7^{III}.
"F" to Road 18 .	Passenger in . . .	171, 169, 153, 37, 151, 7^{I}, 1.
Road 18 to "F" .	Shunt out	2, 3, 7^{II}.
"F" to Table . .	Fly shunt in . . .	37, (*158*), (*175*), (*176*), 7^{III}.
Out Table Road to F	Shunt out	158, 176, 2, 3, 177^{I}.
In Table Road to F	Shunt out	158, 175, 176, 2, 3, 177^{II}.

(Paper No. 2599.)

"The Zurich Water-Supply, Power and Electric Works."

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PART I.—THE ZURICH WATERWORKS.

The town of Zurich, containing, with its ten suburbs, nearly 100,000 inhabitants, is the largest in Switzerland, and may also claim the palm for the magnitude of its public works, carried out and managed by the Corporation. Among these, the new waterworks are especially interesting, not only because the potable-water supply, as well as the motive-power for the waterworks and the electric-installation are derived from the lake, at the lower end of which the town is situated; but also because the experience gained in the management of them leads to important conclusions as regards the comparative cost, performance, and action of roofed-in and open filter-beds; whilst the chemical and bacteriological investigations to which the water-supply is systematically subjected, afford valuable information; bearing, on the one hand, upon the effect of filtration under the most varying conditions, and, on the other, upon the vexed question of the self-purification of rivers.

By the courtesy of the Zurich authorities, the Author was, in the summer of 1891, for the purposes of this Paper, enabled to inspect the works in detail, as well as to examine the methods of analytical and bacteriological control of the water-supply; he also visited the whole basin drained by the lake of Zurich, and collected from official sources in each of fourteen other Swiss towns, data as to their water-supply, together with the registered depths of rainfall at each centre; with a view of placing his researches before the Institution in a comprehensive form. He has treated the subject of his enquiry in three parts, of which the present Paper forms Part I. These several divisions of the Paper comprise the following items :—

PART I.

I. The old water-supply.
II. The typhoid epidemic of 1884.
III. The new water-supply.
IV. The Lake of Zurich.
V. The intake and main conduit.
VI. The filter-station.
VII. The pumping-station.
VIII. Reservoirs and distribution.
IX. Water-supply and rainfall of principal Swiss towns.

PART II.

I. Working of filter-beds.
II. Chemical and bacteriological examination of water.
III. Self-purification of the River Limmat.

PART III.[1]

I. Supply of motive-power.
II. The electric works.
III. Water-supply and electric works (summary).

I. THE OLD WATER-SUPPLY (Fig. 4, Plate 9).

The principle of a mixed water-supply being best suited to local conditions, was originally laid down in 1861, and confirmed in 1873. It was then resolved that the existing spring-water supply should be extended and improved; whilst the supply for domestic, public, and industrial purposes should be taken from the River Limmat (the river that flows from the lake), filtered, pumped up to three reservoirs for distribution, and thence delivered by the Corporation at cost price, after allowing for interest, sinking-fund and renewals. The average yield of the springs is only 660,000 gallons per day, while the pumping-machinery to be erected, and the reservoirs, were designed for a daily supply of, say, 2,200,000 gallons of Limmat water; the total representing, for the then population of 62,000, about 44 gallons per head per day, which at that time was considered ample for all requirements.

Lake-Water Supply.—The pumping-station was originally placed on the left bank of the Limmat, about 1,045 yards below the point of outflow of the river from the lake, water-power amounting to 24 HP. being used for driving two small pumps, to which, in 1870, a steam-engine of 64 HP. and two new pumps were added. In 1871 a sand filter-bed, of 1,360 square yards filtering-surface, was constructed in the bed of the river, at a point about 275 yards below the outflow from the lake; whence the filtered water passed through a concrete conduit 23·6 inches in diameter to the pumping-station. This conduit was, in 1873, extended to an additional pumping-station erected about 550 yards lower down the river, near the Central Railway Station, containing a steam-engine of 59 HP. and two new pumps. This had again to be increased,

[1] This Part iii will appear in a subsequent volume.—SEC. INST. C.E.

in 1875, by the addition of an engine of 68 HP. and two pumps. Thus the motive-power amounted, in 1874, to 215 HP., whilst the consumption of filtered Limmat water already reached 2,860,000 gallons per day (exceeding the estimated maximum by 440,000 gallons), with about 40 miles of mains and 800 hydrants. Four years later, in 1878, owing to a further increase in the consumption, the pumping-machinery was removed to a new site on the right bank of the river, locally known as the "Letten" quarter, where the motive-power was furnished by turbines; the steam-engines being left at the old stations and utilized for other purposes. The additional length of main conduit, made of cast-iron, was about 1,210 yards; so that the total length of conduit from the submerged filter-bed to the Letten pumping-station was 2,530 yards; the latter being situated about 2,805 yards below the outflow of the Limmat from the lake, and 715 yards below the confluence of the Rivers Limmat and Sihl.

Spring-Water Supply.—The average quantity of spring water, collected from about ten groups of small springs in the hills flanking the town, is about 660,000 gallons per day, the minimum yield, however, being only about 190,000 gallons; whilst the ratio of minimum to maximum yield ranges between 1 : 4 and 1 : 26. These fluctuations are due to the thinness of the superficial sand and gravel strata. With the yield of the spring, varies also the velocity of the water; whence, after heavy rain, it is liable to turbidity, arising from the change of velocity, whereby the sand is stirred up; nor does this turbidity disappear until the velocity has again become constant. Generally, the more the temperature of a spring varies with the seasons, the less constant and more superficial is the spring itself. The percentage of rainfall which percolates the soil of the Zurich hills, that is, collects into springs, is carefully measured by pluviometers and percolation gauges.[1] The Author has deduced the following Table of the average annual quantities from the monthly statistics of the last 5 years:—

[1] These infiltration- or absorption-gauges, which have been in use since 1866 are constructed on the principle of the Dalton "lysimeter"; and consist of a square tin box with vertical sides, 1 metre in depth, open at the top and closed at the bottom, sunk into the soil to its full depth, and having at its lowest point a drain-pipe which conveys the percolated water by gravitation to a lower point, where the outflow can be observed and measured. The tin box is filled with the excavated soil, and the surface is covered with turf, so as to restore both soil and surface to their original condition. The quantity of percolated water is measured and determined on the assumption that at the depth of the outflow there is no evaporation, whether the water be in motion or at rest.

Year.	Average Yield of Springs per Minute.	Rainfall per Month.		Percolation per Month.			Average.
		Altitude 480 Metres in the Town.	Altitude 660 Metres on the Hills.	In Plantations.		In Meadow.	
				Cupuliferous.	Coniferous.		
	Gallons.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
1885	372	4·1	3·6	1·3	2·2	1·8	1·7
1886	477	4·3	3·6	1·8	1·4	1·6	1·6
1887	417	3·5	3·0	1·4	1·7	1·5	1·5
1888	582	4·9	4·5	2·4	2·6	2·4	2·5
1889	490	3·9	3·3	2·0	2·5	1·8	2·1
Average of 5 years	468	4·1	3·6	1·8	2·08	1·8	1·9
	(Minimum of 25 years.) 238	(Average of 23 years.) 4·09		50	58	50	52
				Per cent. of rainfall.			

As will be observed, the monthly rainfall in the town (at the Observatory) is 15 per cent. more than on the hills (the difference of altitude being about 590 feet); the mean annual fall in the former locality is 54 inches, and in the latter, 43 inches; whilst the rate of percolation is 15 per cent. more in coniferous than in cupuliferous plantations or meadow land. The mean percentage of percolation or absorption for 5 years is 52 per cent., and for 21 years, 66 per cent., of the registered rainfall; and the greater part of 39 per cent. must be evaporated; as, owing to the nature of the ground, only a small percentage of water flows off the surface. The water of the three principal contiguous groups of springs above Zurich, representing about two-thirds of the entire spring-water supply, passes, before distribution, through a covered filter-bed adjoining the low-pressure reservoir for the filtered lake-water; and is thus effectually freed from the turbidity to which at times it is liable. These springs feed, in addition to house-supply, about 600 public and private fountains; about 25 small and 5 large ornamental fountains being supplied with filtered lake-water. Several of the high-lying suburbs, moreover, have a spring-water supply of their own; and this accounts for the comparatively limited distributing-area of the high-pressure division of the filtered lake-water; although here, too, the consumption of the latter is constantly increasing, owing to the fluctuations, already referred to, of the spring-water. The total cost of the spring-water supply, so far as it is under the

control of the Corporation, including the intake-works, filter-bed, public fountains, and 7 miles of pipes, has been up to the present time £15,000; equivalent to £1 9*s*. 3*d*. per lineal yard. The spring-water supply represents about 14 per cent. of the total water-supply of the town and suburbs.

II. The Typhoid Epidemic of 1884.

In the early spring of 1884, Zurich was visited by a virulent outbreak of typhoid fever, which, beginning in the month of March, reached its maximum intensity in April, and practically disappeared by the end of June, fully 2 per cent. of the population having been attacked, and 9 per cent. of the cases proving fatal. The Commission appointed to inquire into the cause of this epidemic arrived at the conclusion that the infection could not be traced to abnormal meteorological or sanitary conditions; but that the filtered Limmat water, although clear and chemically satisfactory, contained an abnormal quantity of bacteria. It was subsequently discovered that, owing to the dredging operations in connection with the new quay-works, the impure matter deposited at the bottom of the river had been stirred up; and, not being effectually retained by the submerged filter-bed, had found its way into the concrete main, which was by no means water-tight, and had been damaged during the blasting and removal of an erratic block from the bed of the Limmat. The reason why the defective condition of both filter-bed and conduit did not arouse suspicion until after the outbreak of the epidemic was twofold: first, the Limmat water was generally so clear and chemically pure that filtration was considered of altogether secondary importance; and, secondly, the permeability of the concrete, laid at 2 to 3 metres depth below the river-bed, was regarded as an advantage rather than a defect, inasmuch as the sand in which the conduit was imbedded was supposed to act as a filtering medium. The bacteriological investigations, in conjunction with the proved percolation of impure matter through the filter and conduit, stamped the Limmat water as the vehicle of infection; the more so because the typhoid epidemic in Zurich coincided with a similar outbreak at Geneva, where similar dredging operations were in progress, and where the water taken from the lake was, and is to this day, used unfiltered. Hence, at Zurich, the necessity was promptly recognized of providing an entirely new water-supply for the town and suburbs; the dredging-area being in the meantime enclosed, and a cast-iron conduit substituted for the defective concrete main of the old supply.

III. The New Water-Supply.

The daily quantity to be supplied having been provisionally fixed at about 66 gallons per head of population (100,000 inhabitants), the question to be determined was whether this supply could be best obtained from spring, underground or lake water.

In its geological structure, the district of Zurich (Fig. 3, Plate 9) is composed chiefly of the Molasse formation, upon which rests the so-called "Nagelfluh,"—a conglomerate which is in part derived from disintegrated molasse and the detritus of ancient watercourses, but principally from the moraine-matter of ancient glaciers. Of the 13 groups of available springs within and immediately beyond the watershed of the lake of Zurich, there was only one Alpine spring sufficiently copious, situated in the upper Waeggi valley, Fig. 1, at a distance of 30 miles from Zurich, at an altitude of 2,788 feet above sea-level, or 1,444 feet above Zurich, which drains an area of about 3·86 square miles; this, at the considerable rainfall in Alpine valleys of 79 inches per annum, less 25 per cent. for absorption and evaporation, should yield 6,340 gallons per minute, sufficient for a minimum supply of 4,400 gallons per minute at a distance of 30 miles. It was, however, found that the actual total yield of the spring varied between a minimum of 1,320 gallons per minute in the dry season, and a maximum of 52,800 gallons per minute in the wet season.[1] The Author mentions this as an example of the fallacious nature of an estimate of the yield of a spring based simply upon the mean rainfall in a district that embraces several drainage-areas.

The *à priori* objection of insufficient yield of the various groups of spring-water applied equally to the under-ground water, which in and below Zurich, parallel to the Limmat and Sihl, is found at a depth of between 6½ feet and 32 feet below the surface of the ground, as is shown by about 500 wells now used chiefly for agricultural purposes. For this purpose the available area is quite inadequate; nor is the water itself of sufficient purity, subject as it is to infiltrations of impure matter from sewers, from the river Sihl, and other sources. In view of these facts, in

[1] Spring water rising in the upper Alpine reaches is, in spite of its crystalline clearness, peculiarly liable to pollution by the scattered droppings of grazing cattle, unless the whole drainage area is enclosed. Although the water purifies itself to a great extent in the course of its flow, it can produce epidemics by the droppings of diseased cattle, of which cases are recorded in the upper Rhine valley, at Neuchatel and at Appenzell.

conjunction with the chemical and notably the bacteriological inferiority of most of the springs, as well as of the underground water, compared even with unfiltered Limmat water, it was decided to derive the new water-supply entirely from the lake, retaining the existing spring-water supply, and utilizing the original Limmat-water supply delivered by the old conduit exclusively for the supply of motive power.

IV. The Lake of Zurich.

The drainage area of the lake of Zurich, Fig. 1, Plate 9, is about 423 square miles. Its principal tributaries are the rivers Seetz and Linth, both of which rise in the Glarus Alps, and discharge first into the Wallen lake; this latter being in its turn drained by the famous Linth canal, which was constructed in 1822 by Escher von der Linth, for the purpose of regulating the discharge of the Linth and the Wallen lake into the lake of Zurich, and draining the intermediate tract of marshy land. The Wallen lake, which has a superficial area of 9 square miles, and a mean depth of 492 feet, is situated 46 feet above the lake of Zurich. It acts as a vast storage-reservoir for water descending from the Alps; and its purifying action is rendered more effectual by the equable discharge of the Alpine rivers, due to their origin in the glaciers. The lake of Zurich,[1] in addition to the discharge of the Wallen lake, receives the water of the sub-Alpine hills, including the greater part of the yield of those springs, which, if adopted for the supply of Zurich, would have had to be conveyed long distances through costly conduits. Its mean depth is 230 feet. Its mean discharge through the river Limmat is 1,777,000,000 gallons per day. The purifying action of such a lake as this is especially exercised in the precipitation of impure matter, favoured by the slow motion of the water; in extensive oxidation, promoted by the large surface of water which is in contact with the air; by the waters being kept in motion by navigation and by occasional storms; by solar heat which extracts oxygen from aquatic plants; by an aquatic fauna of great variety,

[1] The lake of Zurich owes its origin in the first instance not, as is generally held, to glacial erosion, but to deep rents in the molasse formation which later on facilitated the intrusion and erosive action of the great Linth glacier, advancing and receding in the course of glacial and genial epochs. This is proved by the fact that even at the point of its greatest depth of 475 feet, which coincides with the rent-line, the bottom consists only of soft mud, the rock or true bottom being at a far greater and unknown depth.

which collects at the outflow of drains and streams, and feeds on the impure matter contained in them; and, lastly, by the innumerable quantities of microbes which live at the bottom of the lake, and voraciously devour and destroy the excrements which fall into it from steamers and barges, or may be thrown into it by the riparian population. How effectual is this process of purification in Swiss lakes, may be gathered from the fact that the normal quantity of bacteria in the lake of Zurich, at the lower end, has been found to average 170 per cubic centimetre; in Lucerne 50; in Geneva 38; and in Constance 58 per cubic centimetre; whereas spring-water, especially after rain, often contains as many as 2,000 bacteria per cubic centimetre. Moreover, the water of the lake of Zurich is essentially a soft water; its mean alkalinity, or hardness, being only 8·75 English degrees; whereas the spring-water of the district is 23·1 English degrees, and is therefore suitable only for drinking, and not for cooking purposes. For a town situated like Zurich, hygienic, engineering, and financial considerations alike point to the lake as the proper source of a pure, adequate, and unfailing water-supply; and this is amply attested by the success of the new waterworks, the construction and working of which are described below.

V. The Intake and Main Conduit.

(1) *Intake.*—The point of intake of the lake-water, marked by a buoy, is 919 feet from the nearest quay, the depth of the lake at ordinary water-level being there 56 feet. At first the intake-apparatus consisted of a vertical pipe 35 inches in internal diameter, the upper orifice of which was covered by a screen and surrounded by a wire cage, placed at a depth of 13 feet below ordinary water-level. With the view, however, of obtaining the water at the lowest possible temperature, the intake was subsequently lowered to 46 feet below the surface, or 10 feet above the bottom; for which purpose the upright orifice was closed, and a trumpet-shaped orifice, pointing downwards, was attached to the horizontal main conduit, Figs. 5 and 6, Plate 9. At a lower depth, the proximity of the impure matter deposited at the bottom of the lake was found to impair the quality of the water; whilst, contrary to what on theoretical grounds might have been expected, the water at the depth of 46 feet was as pure as that at 13 feet depth. The comparative temperatures at different depths are shown by the following Table, abstracted by the Author from a series of almost daily tests in 1886, 1887, and 1888:—

Temperature in Degrees Centigrade.	Depth of Intake.			
	13 feet.	39 feet.	46 feet.	52 feet.
Minimum . . .	2°·6	2°·8	2°·9	3°·0
Maximum . . .	17°·3	13°·8	11°·6	9°·4
Mean	9°·9	7°·9	7°·1	6°·3

The increase in the temperature of the water from the intake to the reservoirs, after passing through the main conduit, filter-beds, and pumping-station, is, in the summer months, 2° C. The mean temperature of the water distributed is 9° to 10° C.

(2) *Main Conduit.*—The main conduit, from the intake to the filter-beds, and thence to the pumping-station, consists of four sections of pipes, as follows:—

1st section	351 yards	35 inches in diameter, from the intake to the moat connecting the lake with the river Sihl.
2nd ,,	2,556 ,,	36 inches in diameter, from the moat to the Sihl and the filter-station.
3rd ,,	26 ,,	24 inches in diameter, in the filter-station.
4th ,,	698 ,,	36 inches and 18 inches in diameter, from the filter-station to the pumping-station.
Total,	3,631 yards.	

The three last sections consist of cast-iron pipes; the first is composed of wrought-iron pipes, which were acquired from the St. Gothard Railway, where they had been used for the compressed-air installation of the great tunnel. These pipes rest on a timber frame, composed of three rows of piles connected by cross-beams, the whole containing 11,975 lineal feet of timber. The pumping- and excavation-works of the second section—being the most difficult, owing to the main having to be laid rapidly at an unfavourable season of the year, in a trench 8 feet below the bed of the moat and of the changeable river Sihl—were carried out by Messrs. Locher and Co., of Zurich. The fourth section was carried from the filter-station to the suction-wells of the pumping-station, across the river Limmat, by a foot-bridge 400 feet 3 inches in length; the conduit thus acting as a siphon, in which the water is set to flow in less than ten minutes by means of an air-pump actuated by hydraulic power. This expedient was resorted to owing to the heavy cost of reaching the suction-wells of the pumping-station by gravitation; which would have involved a trench at considerable depth, not only under the river-bed, but under the water-power supply-canal and the foundations of the building. The total cost of the intake works (including

the intake-apparatus, £272) and main conduits, amounted to £16,514; the average cost of main conduit of the different sections laid down being, therefore, 90*s.* per yard.

VI. The Filter-Station.

The site of the filter-station, on the left bank of the Limmat, was selected, on the one hand, because the ground forms part of a tract of land owned by the Corporation, and now chiefly occupied by factories, which utilize the hydraulic motive-power of the waterworks; and on the other, because the construction of the filter-beds near the reservoirs above the town would have involved both inconvenience and unnecessarily heavy expenditure. The system of sand-filtration was adopted in preference to other more or less experimental and costly methods. Nor is there any doubt that sand filter-beds are at once economical and efficient, provided they are constructed, (*a*) so as to give not only pure water, but a given quantity in a given time; (*b*) so as to freely admit atmospheric air, whereby, especially in covered filters, the danger of the development of injurious germs is reduced to a minimum; (*c*) so as to be water-tight and as high above ground as possible, thus preventing the infiltration of under-ground water; and (*d*) so as to admit of easy draining, cleansing, aerating and renewal of the filtering-strata at all times.

(1) *The Filter-beds* (Figs. 7, 8, 9, 10, Plate 9).—The five filter-beds first constructed, including the sand-depot (765 yards × 27 yards) in front of them, below which are placed the eight different conduit-pipes, as well as the clear-water basin and the scour-well for emptying the filters, occupy an area of 7,076 square yards.[1] It was first intended to cover all the filter-beds with arched concrete roofs and a layer of turf; in order, however, to test the comparative action of covered and open filter-beds, the former were limited to three, the two others remaining uncovered for the time being. The excavated material amounted to 19,097 cubic yards, and was used for forming raised pleasure-grounds on one of the new quays of the lake.

The filter-beds are all of the same dimensions, viz., 143 feet 1 inch × 60 feet 10 inches inclusive, and 132 feet 10 inches × 57 feet 5 inches, exclusive of the outer walls; the effective filter-surface being 810 square yards per filter-bed. The average depth

[1] Two roofed filter-beds, of the same dimensions as the existing ones, are now in progress—making a total of seven—and the two beds now open will also be roofed shortly.

of the floor below the surface of the ground is 10 feet. The partition walls between the beds are 4 feet 5 inches in thickness at the footings, and 1 foot 10 inches at the copings; the floor is 14 inches thick, and has an inclination of 1 in 40 in the direction of the two drain-pipes running throughout the length of the bed. On the floor rests the drain-grate, composed of two alternate layers of brick, on which are supported the following filtering strata from bottom to top (Fig. 8):—

	Inches.
One layer of coarse gravel (to fill up spaces between bricks) .	6
,, ,, fine ,, ...	4
,, ,, coarse sand	6
,, ,, fine sand (the filtering medium)	32
Total	48

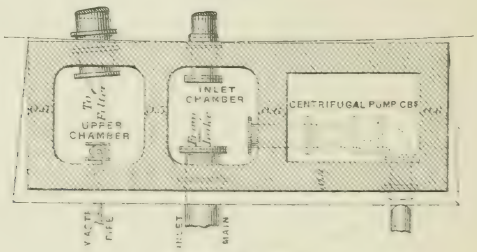
The quantity of sand used is about 1,046 cubic yards for each filter-bed; material specially suited for the purpose being obtained from the upper end of the lake. The sorting, cleaning and washing of the sand, which was at first performed by manual labour, is now effected by a sand-washing machine, actuated by a hydraulic motor, the water from the latter being also used for the washing operation. By means of this machine, 39 cubic yards of fresh sand can be prepared per day for immediate use, at a cost of 8·74*d.* per cubic yard, being two-thirds of the cost by manual labour. The cost of the filtering-material, including setting and stamping, is £100 per filter-bed, equal to 1*s.* 10½*d.* per cubic yard. The roofs of the covered filter-beds are formed of groined arches of 14 feet 9 inches span, 4 feet 1 inch in height, and 8 inches in thickness, resting on 24 concrete piers, the average height of which is 11 feet 6 inches; their mean cross-section being 2 feet 11 inches by 2 feet 3 inches. At the points of intersection of the arches, circular skylights, 2 feet 11 inches in diameter, are provided (36 to each chamber) for light and ventilation. The masonry throughout consists of Portland cement concrete, the proportion of cement, sand, and gravel being, for the walls and floors, 1 to 3 to 6, and for the arches 1 to 3 to 4. All the surfaces in contact with water are carefully lined with cement mortar (1 part of cement to 3 parts of sand) 1 inch thick; and over this surface is spread a thin coating of cement powder, faced, after setting, with a skin of cement-milk. In this way an impervious lining was obtained. When the filters are in operation, the head of water over the uppermost sand stratum is about 3·3 feet; the water-level being about 27½ inches below the coping-stones, of which the upper edge is at the

ordinary water-level of the lake. The filtered water is collected by the two drain-pipes already referred to, and is by them delivered into the return-flow well, whence it passes to the outlet-well. The four wells required for working the filter-beds are all placed in the front wall, which is widened for the purpose (Figs. 9, 10 and 11); while between the return-flow and outlet-wells a sluice-valve is provided for the purpose of regulating the rate of filtration.

(2) *The Clear-Water Basin* (Figs. 11 and 12).—This tank, situated in front of the filter-beds, in the centre of and under the sand-depot, collects the water which has passed from all the filter-chambers through the return-flow and outlet-wells; it is thence delivered through the main to the pumping-station on the opposite side of the river. It is square in plan, with rounded corners, and is 32 feet 10 inches wide by 14 feet 9 inches deep, its capacity being 83,000 gallons. A gauge in this basin indicates at all times whether the rate of percolation through the filter-beds corresponds with the work simultaneously performed by the pumps, and enables the watchman to equalise the supply and demand. Like the filter-chambers, this basin is built in concrete, with an impervious lining; and is surmounted by an arched iron-girder-and-asphalt roof, supported by six columns. The addition of a second basin of equal size is contemplated, so that one may be available when the other is being inspected or cleaned.

(3) *The Suction-Well.*—The water flowing by gravitation from

Fig. 13.



Suction Well.

Scale $\frac{1}{200}$.

the intake in the lake to the filter-station is first discharged into the suction-well, *Fig. 13*, which is placed close to the filter-station on the slope of the river bank. It is 27 feet in depth, and is divided into three chambers. The water coming from the lake is discharged into the middle chamber, out of which it either over-

flows into a second, upper, chamber, whence it is conveyed to the various filter-beds by a pipe 36 inches in diameter; or it can be run to waste direct into the river, when the supply of the filter-beds is to be shut off. The third chamber, which was to serve as the foundation of a wire-rope power-transmission tower, now contains a 30-HP. high-pressure turbine, which actuates a centrifugal pump fitted in a chamber on the top. This is provided for the purpose of lifting the lake-water into the filter-beds, when, at a time of exceptionally low water-level, the supply of lake-water by gravitation is insufficient to meet an increased demand.

(4) *The Filter-Sump.*—This is 15 feet in depth, and is situated under the sand-depot, between the clear-water basin and the suction-well; it consists of two sections connected by a valve, whereby the filter-beds can be emptied by pumping, when this cannot be effected by the drains discharging into the river, owing to floods.

(5) *The Conduits* (Figs. 7 and 11).—These pipes, which are laid under the sand-depot, in front of the filter-beds, are eight in number, all but one being of cast-iron:—No. (1) is the inlet-main, 36 inches in diameter, conveying the water from the suction-well to the filter-beds; No. (2), the overflow pipe, 24 inches in diameter, discharges the overflow from the filters into the river; No. (3) is the filter scour-pipe, 14 inches in diameter, by means of which the filter-beds can be emptied for cleaning; No. (4), the outlet-main, 24 inches in diameter, delivers the filtered water into the clear-water basin; No. (5), 36 inches in diameter, conveys the water from the clear-water basin to the pumping-station; No. (6), 4 inches in diameter, conveys potable water from the low-pressure distributing-pipes in the town, and, by a connection with the return-flow well, serves to fill the filter-beds from below after cleansing; No. (7), the hydraulic-pressure pipe, 2·8 inches in diameter, supplies hydraulic power for driving the sand-washing machine; and No. (8), a cement conduit, 12 inches in diameter, drains the sand-depot. The total length of pipes in the filter-station is 1,084 yards, with 43 T-branches and 33 stop-valves.

(6) *Cost of Construction.*—The construction of the entire filter-station, including £4,800 for Corporation land debited to the waterworks, intake conduit-pipes, wells, and accessory work, was £22,520—equal to an average cost of about £5 10*s.* per square yard of covered and open filtering-surface. The cost of the filter-beds alone, viz., masonry and filtering-material, was £7,360 for the three covered, and £3,280 for the two open, beds—equal to about £3 1*s.* per square yard of covered, and about £2 per square yard of open, filter.

VII. The Pumping-Station.

(1) *Power.*—The waterworks, in common with the power-supply and electric works to be described in the third part of the Paper, use as motive-power the water of the river Limmat, which is partially dammed at a point about 2,000 feet above the pumping-station, immediately above the confluence of the Limmat and the Sihl, and conducted into a supply-canal running parallel to the river. The canal is about 75 feet 6 inches in width, has a fall of 1 in 2,000, and is separated from the river by an earth-work dam. A sluice-lock, 82 feet 3 inches in length, and 14 feet 9 inches wide, connects the head-race with the tail-race, which latter is about 951 feet in length. The cost of the canals, including weir, lock, and sundries, was about £61 per lineal yard.

The fall of the Limmat, and the corresponding volumes of water available for motive power, are as follows :—

(*a*) At high-water level in summer, fall 4·92 feet, volume 2,295 cubic feet per second ; equal to 1,300 HP.
(*b*) At mean-water level in summer, fall 8·20 feet, volume 1,660 cubic feet per second ; equal to 1,570 HP.
(*c*) At low-water level in winter, fall 10·5 feet, volume 1,059 cubic feet per second ; equal to 1,280 HP.

Hence, at 80 per cent. efficiency of the absolute water-power, the mean effective motive-power, in respect of the turbine-shafts, is 1,100 HP., and is utilized for the following purposes :—

	HP.
(1) For pumping the potable- (filtered) water supply . .	237
(2) For supplying motive-power by hydraulic pressure . .	128
(3) For supplying motive power by wire-rope transmission	227
(4) For supplying hydraulic motive-power for the electric-lighting installation	444
Total	1,036

In the event of the available water-power, at exceptionally low water-level of the Limmat, being reduced to 592 HP. effective (when the fall is 10·5 feet and the volume only 883 cubic feet per second), the deficiency is supplied by two reserve steam-engines of 296 HP. (effective) each. The total hydraulic power will meet the demand for the next five or six years. The additional power then required for the water-supply, which increases at the rate of 5 per cent. per annum, and for extension of electric lighting, may readily be obtained by electric transmission at a high potential,

either from the river Limmat below Zurich, from the river Reuss, or from the Rhine, the distance from these points being about 20 miles.

(2) *Buildings and Machinery.*—The entire hydraulic machinery, as well as the recently-added electric-plant, including reserve steam-engines, are contained in a brick building 377 feet 4 inches × 75 feet 6 inches, the foundation of which is in part formed by twelve turbine-chambers, each 31 feet 6 inches in depth, composed of three superposed arched concrete divisions, of which the middle one constitutes the inlet, and the lowest the outlet, chamber. The iron roof of the building is supported by two rows of iron columns inside the machine-room, in which are three overhead travelling-cranes. The building is heated by two stoves with ventilators, and is lighted by electricity; whilst an electric regulator and the four automatic indicators, registering the differences of water-level in the various reservoirs down to about 2 inches, are fixed on the wall. The steam-boilers, as well as the sheds, smithy, and offices, are placed in a separate wing adjoining the electric installation. The area of the building, including the new electrical section, outside wing, and depots, is 40,904 square feet. The total cost of the land and buildings, including turbine-chambers and fittings, was £56,120.

The pumps are actuated by 10 turbines; a reserve of power being afforded by 2 reaction turbines, of 172 HP. each, recently put down in connection with the electric-supply. All these turbines are of the Jonval type, built as reaction turbines, with three or two concentric rings. In eight of them, the diameter is 11 feet 9·73 inches, the number of revolutions increasing at times from 25 to 37 per minute, their tested efficiency in work, measured on the vertical shaft, being as follows:—

(*a*) At maximum fall and minimum volume of river Limmat—75 per cent.
(*b*) At minimum fall and maximum „ „ „ —85 per cent.

Hence, their effective power is:—

in case (*a*) 94·68 brake HP.
(*b*) 108·49 brake HP.

The power developed by each pair of turbines is transmitted from the vertical shaft by bevel-gearing to a horizontal shaft, which, in the case of the first 8 turbines, makes 50 revolutions, and in that of the 2 latest, 66 revolutions per minute; thence, the power is transmitted by pinions to the main shaft, which is of steel, 7·6 inches in diameter, making 100 revolutions per minute. This shaft

is about 328 feet in length, and passes throughout the length of the building; so that the whole of the turbine-, pumping-, steam-, and electric-machinery can be coupled to it separately or jointly, as and when required. The collective effective power of the 10 turbines is 1,130 HP. They were all supplied by Messrs. Escher Wyss and Co., of Zurich, at a cost of £1,220 for each of those developing 98 HP., and £1,260 for each of those developing 172 HP., including gearing and horizontal shaft. The total cost was £12,320.

There are at present in operation 7 sets of horizontal compound Girard pumps, each set comprising two pumps, and having its own suction air-vessel, while 3 of the sets have each two pressure air-vessels, and the other 4 sets have one pressure air-vessel each. The dimensions of the several sets are as follows:—

	First Type Three Sets.	Second Type Three Sets.	Third Type One Set.
	Inches.	Inches.	Inches.
Diameter of piston	11·41	9·05	11·41
	Sq. Ins.	Sq. Ins.	Sq. Ins.
Area „ „	102·3	64·33	102·3
	Inches.	Inches.	Inches.
Length of stroke	23·62	35·43	23·62
Number of double strokes per minute	25	25	37·5

The total pumping-capacity of the 7 sets is 8,143,600 gallons per day. An eighth set of pumps of the third type is now being put down as reserve, with space for 2 additional sets.

The cost of the pumps of the first type was £1,616 per set, and of the second £1,928 per set; whilst the third type, which delivers 50 per cent. more water, and works with ease up to 50 revolutions per minute, only cost £2,024 complete, or 10 per cent. more than the others. The total cost of the pumping-machinery, including main shaft, cranes, gauges, indicators, and sundries, which were also supplied by Messrs. Escher Wyss and Co., of Zurich, was £15,160.

VIII. Reservoirs and Distribution.

(1) *Reservoirs* (Fig. 4, Plate 9).—From the suction-wells of the pumping-station, the filtered lake-water is pumped up to 3 covered reservoirs (low, medium, and high pressure) for distribution to the low-, medium-, and high-pressure divisions respectively of the town and suburbs; whilst the Limmat water of the old

conduit is pumped up to a fourth open tank for the supply of hydraulic power.

The differences of level between the pumping-station and these 4 reservoirs, the mean lift (suction and pressure), the lengths and diameters of pipes, and the cubic capacities of the reservoirs are as follows:—

—	Altitude above Sea Level.	Difference of Level.	Mean Lift.	Length of Main.	Diameter of Main.	Capacity of Reservoir.	
						Present.	To be increased to
	Feet.	Feet.	Feet.	Feet.	Inches.	Cubic Feet.	Cubic Feet.
Mean water-level of lake	1,342·0	..	..	..	..	..	..
Coping-stones of filter-bed walls .	..	..	..	..	..	..	..
Floor of filter-beds .	1,329·0	..	..	..	..	..	..
Water-level in pump-suction wells . .	1,325·48	..	..	..	..	..	..
Water-level in low-pressure reservoir	1,479·68	154·20	229·66	8,858	12·16	204,836	..
Water-level in medium-pressure reservoir . . .	1,624·03	298·56	374·02	7,874	10·18	68,514	141,266
Water-level in high-pressure reservoir	1,811·05	485·57	528·22	9,186	8·10	10,595	21,190
Water-level in tank (hydraulic accumulator) . . .	1,855·70	528·22	554·47	5,577	18·00	353,170	529,750

The power employed in pumping is 420 HP.[1]

The lower- and medium-pressure reservoirs are built of brick, and the recently-constructed extension of the former is of concrete, the thickness of walls being 59 inches, while the arches are 10 inches in thickness, 14 feet 9 inches wide between the springings, and 27 inches in height. The depth of the reservoirs is between 13 feet and 14 feet 9 inches; the lower reservoir has 26, and the upper 8, ventilating shafts; and both are covered with a layer of turf 3 feet 3 inches in depth. The intermediate walls, 20 inches in thickness, which support the groined arches, divide the reservoirs into oblong chambers, 11 feet to 14 feet 9 inches in width;

[1] The power required to pump 1 ton of water to the four reservoirs works out respectively at 0·24, 0·45, 0·48, and 1·3 HP. per hour. The filtered lake-water is to a great extent distributed direct without passing through the reservoirs, which consequently serve, in the main, only to store the surplus water. The quantity pumped per day to the four reservoirs is 13,000, 5,000, 250, and 3,500 tons respectively.

and thus circulation of the water is ensured—the play of valves being so arranged as to cause the water, after entering the reservoir, to flow through 8 chambers in the lower, and 13 in the upper, reservoir before it reaches the outlet. The third, or high-pressure, reservoir, which is likewise built of cement concrete, is circular in plan, 32 feet 2 inches in diameter. In addition to the extensions of these reservoirs now being carried out, another small low-pressure reservoir of 10,595 cubic feet capacity is to be constructed on the Uetliberg side of the lake, at an altitude of 1,444 feet above sea-level, or 118 feet higher than the pumping-station, and at a distance of 14,436 feet from the latter. The open reservoir or hydraulic accumulator will be referred to in the third part of the Paper on the supply of power. The cost of the three reservoirs, of an aggregate capacity of 1,800,000 gallons, was £12,920.

(2) *Distribution.*—The distribution in the low-, medium- and high-pressure divisions is on the "trunk-and-branch" principle, with main and subsidiary pipes and connecting-valves; but is worked for the most part on the circulation system, in order to prevent the supply from running short in any one part of the town or suburbs. The pipes are all laid 5 feet below the surface of the ground, and the large number of stop-cocks allows the shutting-off of the supply, when necessary, to be restricted to the smallest possible area. The length of main and service-pipes, which vary between 16 inches and 1·6 inch in diameter, is 72 miles, owing to the extensive area of distribution in the suburbs. The fire-hydrants are placed about 66 yards apart, close to the edge of the curb, and can be used for scouring purposes, in addition to the ordinary flushing-valves. The total cost of the distribution system, including 752 valves and 1,294 hydrants, was £81,000.

IX. Water-Supply and Rainfall of Principal Swiss Towns.

For the purpose of comparison with the Zurich water-supply, as well as with a view to giving a general idea of waterworks in Switzerland, the Author has obtained from the local authorities, data of the potable-water supply of the principal towns; and from these data he has prepared Table I, Appendix, giving for each town the daily consumption, the cost of construction of the works, and other information. Table II presents the annual rainfall of each town, of the principal lakes on both sides of the Alps, and the monthly rainfall at Zurich; being compiled from statistics

obtained from the Central Swiss Meteorological Office at Zurich. The data for the annual rainfall of the towns and lakes refer to 1888, an unusually rainy year, whilst the average rainfall over a period of 20 years is also given.

An examination of the Tables shows:

(1) That the average consumption of potable water is 53 gallons per head per day; the highest rates of consumption being 100 to 125 gallons per head per day at Montreux, Neuchâtel, and Bienne. The high rate in the last three cases is accounted for by the fact that, in those towns, the water is chiefly supplied by rate, instead of by measurement; this latter system being exclusively adopted only at Basle, where the measured consumption in 1890 was 31 gallons per head of total population: (2) That the average length of main is about 10 miles, the greatest lengths of main being at Basle, Lucerne, Lausanne, and St. Gall: (3) That the cost of works per head of population is over £3; the lowest being £1 7*s*., at Montreux; and the highest at Geneva and Neuchâtel, viz., £4 16*s*. and £7 6*s*. respectively: (4) That the average return on the capital invested is 8 per cent., the highest being at Basle, Montreux, and Bienne, viz., 9·5, 10·5 and 12 per cent. respectively: (5) That of the fifteen towns referred to, ten are supplied exclusively with spring-water; one (Fribourg) with river-water; and four (Zurich, Geneva, Lausanne and St. Gall) with lake-water; the mean temperature being 48°·2 F., and that of the spring-water being not only not lower, but in several cases actually higher than that of river- and lake-water: (6) That at Zurich, Fribourg, and St. Gall, the lake- or river-water is filtered, whereas at Geneva it is used unfiltered: (7) That all the principal towns have not only an adequate but an abundant supply of potable water, with the single exception of Lugano, which, although highly favoured by Nature, and a favourite resort of visitors and tourists, has not, up to the present time, a regular or uniform water-supply: (8) That the annual rainfall of Lugano is 42 per cent. greater than that of Zurich, that of the lakes south of the Alps being 35 per cent. greater than that of the northern lakes; and (9) that the greatest monthly rainfall in Switzerland generally takes place in the summer.

The earnings upon which the returns are based, are equal to about 3·5*d*. per 1,000 gallons; the highest being those of Basle, although even there the receipts do not represent more than 5·6*d*. per 1,000 gallons. With the exception of Lausanne, Montreux, and Herisau, in the two former of which the water is supplied by companies, and in the latter by a local syndicate, the waterworks of all the

towns are owned and worked by the Corporations, the supply being given at cost price after covering interest, sinking-fund and renewals; and the fact that, even at the low rates charged, the yield of the capital invested is as high as 9 per cent., in itself affords proof that the working of waterworks is eminently the province of municipal authorities. Moreover, the considerable expense incurred by the various Corporations in procuring good water, either from more or less distant sources of supply, or by costly hydraulic works such as those of Zurich and Geneva, shows how keenly alive they are to the hygienic importance of a good and adequate supply, not only in their own local interest, but in that of the numerous visitors to Switzerland.

The most eloquent proof of the beneficial effect of the filtered lake-water supply on the sanitary condition of the town of Zurich, is afforded by the fact that the number of ordinary typhoid cases, which, under the old supply, was, in 1880, 4 per 1,000 of the population, has now, in 1891, dropped to 0·4 per 1,000—representing a diminution of 90 per cent. From a hygienic, no less than from a scientific and engineering point of view, the Zurich Waterworks are undoubtedly, not only among Swiss towns, but on the Continent generally, a model of how such works should be constructed and worked; and, looking to the fact that the lake of Zurich provides not only an inexhaustible supply of pure potable water, but also motive-power for delivering that supply, as well for a variety of industrial works and for electric-lighting, it may with truth be said that that lake is at once the ornament and the source of health and wealth of the town and its suburbs.

For information kindly furnished him, the Author has to express his obligations to Dr. W. Burkhard, Engineer-in-Chief to the Corporation; and to Dr. A. Bertschinger, Director of the Municipal Laboratory; also to Dr. A. Bürkli, Engineer-in-Chief of the Corporation Quay Works, and to Dr. R. Billwiller, Director of the Central Swiss Meteorological Office in Zurich; and he is further indebted to the courtesy of the engineers of the fourteen other Corporations for the data which enabled him to prepare the Table of Water-supply of Swiss Towns.

Part I of the Paper is illustrated by drawings from which Plate 9 has been prepared.

APPENDIX.

TABLE I.—WATER-SUPPLY OF PRINCIPAL SWISS TOWNS.

1889.	Altitude above Sea-Level.	Total Population.	Consumption.		Length of Main.	Cost of Works.		Return on Capital Expenditure.	Mean Temperature of Water.	Spring, River or Lake Water.
			Total per Day.	Per Head per Day.		Total.	Per Head of Population			
	Feet.		1,000 Gallons.	Galls.	Miles.	£.	£. s.	Per Cent.	Fahrenheit.	
Zurich	1,351	93,000	4,730	50	2·05	352,600	3 15	6·75	50°	Spring and filtered lake.
Basle[1]	869	72,500	2,270	31	13·79	125,600	1 14	9·5	50°	Spring.
Geneva[2]	1,240	52,640	2,780	50	7·77	226,800	4 7	9·0	48°	Unfiltered lake.
Berne	1,758	47,150	2,220	48	12·92	106,300	2 5	7·0	50°	Spring.
Lausanne[3]	1,686	34,050	2,220	59	18·64	93,300	2 16	3·75	50°	Lake Bret.
St. Gall[4]	2,198	27,840	790	28	25·17	120,000	4 5	7·5	46°·4	Spring and filtered lake.
Chaux de Fonds	3,274	25,840	780	30	11·56	80,000	3 2	9·0	48°·2	Spring.
Lucerne	1,437	21,300	1,050	50	17·09	71,700	3 8	6·5	48°·2	,,
Vevey-Montreux	1,240	19,110	1,920	100	7·89	26,400	1 7	10·5	45°·5	,,
Neuchâtel[5]	1,434	16,500	1,660	100	12·43	120,000	7 6	6·5	46°·4	,,
Winterhur	1,450	15,960	960	60	5·90	60,000	3 13	7·0	50°	,,
Bienne[6]	1,430	15,410	1,920	124	2·48	25,500	1 13	12·0	50°	,,
Herisau[7]	2,546	12,970	450	35	3·11	18,000	1 8	9·5	46°·4	,,
Schaffhausen	1,296	12,400	670	54	2·05	18,200	1 10	9·0	49°	,,
Fribourg[8]	2,100	12,240	1,050	86	1·24	38,000	3 4	7·0	48°·2	Filtered river-water.
Lugano[9]	902	7,169	..	..	..	..	..	..	..	..
Totals	..	486,080	25,470	855	144·09	..	..	..	..	..
Averages	..	..	..	53	916	..	..	8	48°·2	..

[1] Basle; under-ground water pumped when spring-water is insufficient.

[2] Geneva; between 8,000,000 and 13,200,000 gallons of lake-water are delivered per day for industrial and public purposes, in addition to the above potable supply.

[3] Lausanne; a spring-water supply by various companies of 1,892,000 gallons per day, in addition to the above supply by "Lac de Bret" Company.

[4] St. Gall; above figures include 528,000 gallons per day of water to be derived from Lake Constance and pumped to the town-reservoirs—distance 13·7 miles, difference of level between lake-level and town 892 feet—by water-power of the River Goldach. Temperature of water at 164 feet depth, 39° F.

[5] Neuchâtel; the spring of the Reuse valley, in the Jura, gives normally 1,900,800 gallons per day; but the yield has of late years fallen about 17 per cent.

[6] Bienne; the normal yield of the spring, in the Jura, is 6,380,000 gallons per day; the average of the last four years is 60 per cent. less than that quantity.

[7] Herisau (Appenzell); the above data comprise supply from private springs and water delivered by a local syndicate.

[8] Fribourg; the water of the River Saline is also used for motive-power by rope-transmission.

[9] Lugano; there are several schemes for a regular potable water-supply; but none has yet been carried out.

TABLE II.—RAINFALL IN SWITZERLAND.

(1) *Towns.*

—	1888.			1864 to 1883.	Altitude above Sea-Level.
	Greatest Rainfall per Day.	Number of Rainy Days.[1]	Average per Annum.	Average per Annum.	
	Inches.		Feet.	Feet.	Feet.
Zurich	2·1	153	5·00	3·79	1,351
Lake Zurich (watershed)	2·3	131	4·95	..	1,342
Basle	1·5	130	2·25	2·75	869
Geneva	5·0	132	3·31	2·79	1,240
Berne	3·6	153	3·66	3·60	1,758
Lausanne	3·8	160	4·00	..	1,686
St. Gall	6·0	170	6·15	4·65	2,198
Chaux de Fonds	2·5	157	4·80	..	3,274
Lucerne	2·8	152	4·35	..	1,437
Montreux	2·2	137	3·78	..	1,240
Neuchâtel	2·9	145	3·15	3·20	..
Winterthur	2·7	158	4·95	..	1,450
Bienne	4·4	150	4·10	..	1,430
Herisau	4·0	154	4·35	..	2,546
Schaffhausen	2·2	127	3·27	..	1,296
Fribourg	3·2	137	3·86	..	2,100
Lugano	5·0	146	8·15	5·40	902
Average	3·3	140	4·36	3·75	..

(2) *Lakes.*

—	In Twenty Years.	Altitude.	Area.	Greatest Depth.
	Average per Annum.			
	Feet.	Feet.	Square Miles.	Feet.
Constance, at Trogen St. Gall	4·56	1,306	207·85	905[2]
Zurich, at Zurich	3·79	1,342	34·00	466[2]
Lucerne, at Altdorf	3·74	1,434	43·62	853[2]
Neuchâtel, at Neuchâtel	3·20	1,427	92·05	472[2]
Geneva, at Geneva	2·79	1,230	224·11	984[2]
Maggiore, at Locarno	4·90	646	82·61	1,130[3]
Lugano, at Lugano	4·85	889	19·30	918[3]
Como, at Castasegna	5·40	697	60·21	1,358[3]
Average	4·15	..	..	..

[1] "Rainy days" are those on which the rainfall is 0·02 inch or more.

[2] Average rainfall of lakes north of Alps is 44 inches per annum in 20 years.

[3] Average rainfall of lakes south of Alps is 60 inches per annum in 20 years.

APPENDIX—TABLE II *continued.*—RAINFALL IN SWITZERLAND.

(3) *Zurich.*

	Monthly Rainfall at Zurich Observatory.							Monthly Rainfall on Hills.		Percolation in Meadows and Plantations.	
	1885.	1886.	1887.	1888.	1889.	Average of Twenty-three Years.		Average of Twenty-one Years.		Average of Twenty-one Years.	
	Millimetres.	Millimetres.	Millimetres.	Millimetres.	Millimetres.	Millimetres.	Inches.	Millimetres.	Inches.	Millimetres	Inches.
January . .	8·0	47·7	10·6	35·0	24·2	42·7	1·66	15·4	0·60	33·2	1·29
February . .	83·9	40·8	8·8	37·6	99·2	57·0	2·22	92·3	3·60	54·8	2·14
March . .	109·1	61·0	109·6	137·9	67·4	94·3	2·78	54·7	2·13	74·3	2·89
April . . .	46·2	108·5	63·2	149·8	76·0	103·1	4·01	67·6	2·64	56·8	2·21
May . . .	187·3	72·2	199·2	73·2	104·3	118·8	4·63	86·1	3·38	63·9	2·49
June . . .	84·9	225·9	43·4	190·2	180·7	156·1	5·09	139·1	5·82	78·9	3·08
July . . .	105·0	174·5	154·3	275·8	135·6	138·2	5·39	129·7	4·97	47·6	1·86
August . .	75·3	193·0	122·8	162·2	127·0	137·4	5·36	134·8	5·26	45·4	1·77
September .	194·6	62·1	118·9	246·5	106·5	120·9	4·71	97·1	3·78	53·0	2·07
October . .	172·2	109·3	46·6	107·6	144·8	122·9	4·70	101·3	3·95	50·2	1·96
November .	76·8	84·1	44·2	56·1	67·1	64·8	2·52	63·6	2·48	53·2	2·07
December .	119·1	145·9	131·9	32·5	44·8	94·6	3·69	29·8	1·16	60·4	2·35
Monthly Average	105·2	110·44	87·8	125·3	98·1	104·2	4·06	84·3	3·29	56·0	2·18
	Average of five years 105·4 millimetres per month.							Average percentage of percolation in 21 years is 66 per cent.			

PART II.—PURIFICATION OF WATER AT ZURICH.

I. Working of Filter-beds.

(1) *Filtration at Varying Rates.*—In the course of the last few years, a series of investigations have been made at the Zurich Waterworks for the purpose of testing the effect of filtration at various rates up to 3,700 gallons per square yard per twenty-four hours; with a view to ascertain whether the existing rate (1,100 to 1,800 gallons per square yard per twenty-four hours) could be safely increased; or whether additional filter-beds should at once be constructed to meet the constantly growing demand. The average results which the Author has compiled from about 300 analyses[1] are as follows:—

Chemical Constituents of the Filtered Water are stated in parts per 1,000,000.	Rate of Percolation per Twenty-four Hours.				
	Up to 750 Gallons per Square Yard.	Up to 900 Gallons per Square Yard.	Up to 1,500 Gallons per Square Yard.	Up to 2,800 Gallons per Square Yard.	Up to 3,700 Gallons per Square Yard.
Organic matter	16·5	16·9	17·0	17·0	20·2
Ammonia	0·007	0·008	0·004	0·004	0·006
Albuminoid ammonia . . .	0·028	0·027	0·027	0·027	0·037
Bacteria per cubic centimetre	20	31	22	15	18

These results show, therefore, that, provided the filter-beds are in efficient working-order, neither the chemical nor the bacteriological purity of the filtered water is impaired by increasing the rate of percolation from 1,025 gallons to 2,800 gallons per day, a fact which is at variance with the view advanced elsewhere, that the mean rate of percolation for sand-filters should be limited to 550 gallons per square yard per twenty-four hours.

(2) *Filtration under Exceptional Conditions.*—In the year 1880, when, after an exceptionally severe winter, the ice on the lake broke up, there was a considerable increase of the normal number of typhoid cases; and this was not unreasonably attributed to

[1] Municipal Laboratory, Zurich, Dr. A. Bertschinger, 1889.

probable contamination of the Limmat water passing through the old submerged filter and concrete main. It was therefore feared that a similar phenomenon might recur after the still more severe frost of the winter 1889–90, during which the entire lake was frozen over from the end of January to the end of March; and that the impure matter accumulated on the surface of the ice might, after the thaw, pass into and contaminate the new water-supply. A series of about 50 special analyses were therefore made between January and May, with the view of ascertaining whether, and how far, the quality of the unfiltered and filtered water would be affected during the frost, and during and after the thaw. From the results of these analyses,[1] the Author has deduced the statement given in Table I, covering five consecutive periods: viz., immediately before the lake was frozen over; during the frost; upon the thaw setting in; after the thaw; and until the lake-water returned to its normal condition :—

TABLE I.

Chemical Constituents expressed in parts per 1,000,000	15 Nov., 1889, to 17 Jan., 1890, Normal.	18 Jan., 1890, to 19 March, Lake Frozen over.	20 March, 1890, to 5 April, Lake open.	6 April, 1890, to 12 May, immediately after Thaw.	13 May, 1890, to 27 June, Normal.
Before filtration—					
Organic matter	16·9	18·3	17·7	18·0	18·3
Ammonia	0·007	0·009	0·007	0·005	0·005
Albuminoid ammonia	0·028	0·032	0·030	0·029	0·033
Bacteria per cubic centimetre	122	667	938	632	171
,, (maxima)	202	2,179	2,152	1,425	229
Mean temperature of water ° F.	+41°·4	+37°·4	+39°	+40°	+48°·2
Mean temperature of Air ,,	−15°	−16°	+40°	+45°	+57°·2
After filtration—					
Organic matter	14·1	14·4	14·0	14·1	14·9
Ammonia	0	0	0	0	0
Albuminoid ammonia	0·018	0·019	0·019	0·020	0·019
Bacteria per cubic centimetre	10	13	9	11	16
,, (maxima)	20	27	29	22	21

The above indicates: (1) A sudden and large increase of bacteria a fortnight after the lake was frozen over, then alter-

[1] Municipal Laboratory, Zurich, 1891.

nately rising and falling until it returned to the normal number: (2) That these violent fluctuations were quite independent of the temperature either of the air or of the water: (3) That the great increase of bacteria during the frost is probably due to the natural process of oxidation being impeded by the exclusion of air from the water; whilst the high rate of bacteria during the thaw is due to the impure matter collected on the ice becoming mixed with the water when the ice melted: (4) That, throughout these bacteriological fluctuations, the chemical composition of the water shows but slight and inappreciable changes from its normal condition; hence the importance of bacteriological investigations: (5) That, throughout the fluctuations in the quality of the unfiltered lake-water, the filtered water continued of good quality; showing that the filter-beds performed their duty effectively.

(3) *Comparative Cost and Working of Covered and Open Filter-beds.*—The action of both the covered and open filter-beds is subjected to constant tests; and the working of the last 4 years affords interesting information respecting their comparative working-cost and efficiency. The loss of head, due to the resistance of the filtering strata, is measured three times a day at every filter-bed; and the filter-beds are cleaned when the difference of level between the unfiltered and the clear water attains 24 to 32 inches. The water is then drawn off by the filter-scour conduit and well; a layer of about $\frac{3}{4}$ inch is, by means of iron spades, carefully removed from the surface of the sand, the thickness of which, when new or renewed, is 32 inches. This cleansing operation has to be effected after about 50 days' work in the covered, and about 40 days' work in the open, filters; and when, after successive cleansings, the sand stratum has been reduced to a minimum of 12 inches, the filter-bed is either replenished with carefully-washed sand, or the entire filtering-material is renewed. After this operation, the filter-bed is refilled from below with filtered water through the return-flow well; and, upon the filter-bed being thus again rendered efficient, the filtered water is at first allowed to flow to waste, until it is proved to be chemically and bacteriologically pure. This last period occupies, in the case of entire renewal, between 11 and 20 days, and, in the case of cleansing, about 12 hours. In 4 years, the sand was renewed in 3 filter-beds after 2 years' working; and, in the other 2 filter-beds, the entire filtering-material was renewed after 3 years' working. The average cost of cleansing and partial re-filling with sand is about £1 14*s.* 5*d.* exclusive of, and £2 3*s.* 2*d.* inclusive of, the

sand;[1] that of renewing the entire layer of sand is £34; and that of renewing the whole filtering-material is £100 per filter-bed—equivalent to 18 pence and 22 pence respectively per cubic yard of filtering-material. In comparing open with covered filter-beds (Table I, Appendix), it is found that the maintenance and cleansing of the open filter-beds is attended with much greater difficulty than that of the covered ones. Owing to solar action during the summer, a film of green algae forms on the surface of the sand, and increases the loss of head through the filtering-strata; hence the open filter-beds require more frequent cleansing than the covered ones, which latter, though ventilated, are kept dark. Again, in winter, the ice that forms on the surface of the open filter-beds renders the cleansing of these beds both more costly and troublesome than that of the covered ones.

The Author draws the following conclusions from the statistics furnished in Table I of the Appendix:—(1) The open filter-beds require 50 per cent. more cleansing than the covered ones: (2) The covered filter-beds filter 14 per cent. more than the open ones: (3) The cost of filtration is 10 per cent. less by the covered than by the open beds; whilst the cost of construction of the covered beds exceeds that of the open ones by 27·5 per cent. Hence the lower cost of construction of the open filter-beds does not compensate for their higher cost of maintenance and their lower yield as compared with covered beds. The Zurich authorities have, therefore, decided to roof not only the two open filter-beds, but also the five new ones. It should be added, however, that in point of quality of the filtered water, no appreciable difference has been found between covered and open filter-beds.

II. Chemical and Bacteriological Examination of Water.

Both the unfiltered and filtered lake-water, as well as the spring-water supply, is subjected to fortnightly, and often weekly, chemical and bacteriological examination in the Municipal Laboratory. The samples of the unfiltered water are taken in the lake, at a depth of 46 feet, by means of exhausted glass bulbs, each of

[1] The cleansing of the old submerged Limmat filter and removal of a layer of about 3 inches of sand, which can only be effected by divers, costs about £80.

which has its neck drawn out into a loop closed at the end, and is opened to admit the water by breaking the loop at the required depth. The samples of the filtered water are taken at the pumping-station before the water is distributed, and also at various points of the distributing-area. Samples of the spring-water are similarly taken before and after filtration. Besides this regular examination, special analyses are constantly made of the lake-water, taken at depths varying between 13 feet and 52 feet; of the water immediately before it enters, and after it leaves the filter-beds; and also whenever the quality of the water is liable to be affected by special phenomena, such as severe frosts. The ordinary chemical and bacteriological tests average about 250 per annum, and, to ensure uniformity, are conducted according to fixed methods, which in some respects differ from, and give more accurate results than, those usually employed, and of which the Author therefore gives a short outline, as follows :—

(1) *Chemical Analysis.*—(*a*) Dry residue, obtained by evaporating the water and drying the residue at 100° C.

(*b*) Glow residue, obtained by heating the dry residue to white heat; after moistening with carbonate of ammonia, it is dried again at 150° C.

(*c*) Hardness. The glow residue is treated with hydrochloric acid and methyl orange; the degree of hardness of the water is determined by the quantity of carbonate of lime and magnesia found in it.

(*d*) Organic matter, determined by titration. This determination, to which generally so much importance is attached, is, however, no criterion as to whether the organic matter is harmless or injurious; although water containing much organic matter shows that microbes, which feed upon it, are more likely to multiply in it than in water containing less organic matter.

(*e*) Ammonia, and (*f*) Albuminoid ammonia,—Wanklyn's method.

(*g*) Nitrous acid, qualitative test, by iodide of potassium and starch, with a slight addition of sulphuric acid.

(*h*) Nitric acid, qualitative test, by diphenylamine reaction in concentrated sulphuric acid.

(*i*) Sulphates (sulphate of lime), qualitative test, by treating 100 cubic centimetres of the water with a few drops of hydrochloric acid and solution of chloride of barium.

(*k*) Chlorides (chloride of potassium), qualitative test, by nitric acid and nitrate of silver.

Good water should contain less than 35 parts in 1,000,000 of organic matter, no nitrous acid, less than 5 parts of nitric acid,

less than 0·02 part of ammonia, and less than 0·05 part of albuminoid ammonia.

As may be seen from the standard analysis, Table II, the lake-water contains only slight traces of chlorides, sulphates and nitric acid, and no nitrous acid; hence the regular analysis is quantitative for organic matter, ammonia and albuminoid ammonia; the other substances being tested only qualitatively, unless the tests point to their being present in any appreciable quantity.

(2) *Bacteriological Control.*—This is limited to determining the number of bacteria per cubic centimetre of water; the differentiation according to species being, for the purposes of water-supply, both unnecessary and unreliable, unless an abnormal number of bacteria, in conjunction with an unfavourable chemical analysis, points to probable contamination. The cultivation of bacteria is conducted according to Professor Koch's method, modified by Professor Cramer, of Zurich,[1] the salient features being as follows:—

The bottles, or Erlenmeyer receivers, used for the cultivation, are of the thinnest white glass, with cotton stoppers, 12 centimetres high and 9 centimetres in diameter at the bottom. These receivers, and the small bottles and sink-bulbs containing the water to be tested, as well as the gelatine test-cylinders and the pipettes for measuring the water, are sterilised by being heated for two hours to 150° C. The gelatine for cultivating the bacteria is prepared according to Buchner's method (50 to 100 grammes, according to the season, of white gelatine, with 5 grammes of Liebig's meat-extract, 5 grammes of peptone, and 20 grammes of sugar), latterly also, according to Löffler's direct meat-extract and peptone method; it is then dissolved in distilled water, made distinctly alkaline, boiled with water so as to bring the liquid up to 1 kilogramme, filtered hot, and poured into the test-tubes, in which it is intermittently sterilised in Dr. Koch's sterilising-apparatus, and kept for 10 minutes at boiling-point at least 6 times in the space of 10 days. Of the gelatine so prepared, 3 to 4 cubic centimetres are then introduced into each glass receiver, to which is added 0·5

[1] Professor Cramer's method (of using "receiver-bottles") has over Professor Koch's so-called "plate" method the advantage of greater simplicity and rapidity of cultivating bacteria, and offers, moreover, greater protection against the intrusion of extraneous germs. For purposes of bacteriological tests of water, viz., counting, and not differentiating, the bacteria, Professor Cramer's method is also preferred to Petri's method of using glass boxes, and to Esmarch's "test-tubes."

centimetre, carefully measured by a pipette, of the water to be tested; whereupon each receiver is closed with its cotton stopper, and is gently agitated until the gelatine and water are thoroughly mixed. After cooling, the receivers are suspended for observation bottom upwards, the bacteria being then counted by means of a microscope. The bacteria are counted every day from their first appearance, and the counting is stopped when the gelatine begins to liquefy. The last counting, generally between the fourth and eighth days—according to the season—is decisive, and from it the number of bacteria per cubic centimetre is determined. For the purpose of comparison, two samples of each water are always taken and tested simultaneously. The water is put under cultivation with as little delay as possible, being kept in a refrigerator at from 43° to 50° F., in order to prevent the germs from multiplying. Before adding the water to the gelatine in the receivers by means of pipettes, it is thoroughly shaken, so as to distribute the germs equally; whilst the gelatine (which melts at 80° F., and solidifies at 68° F.) is cooled down to 86° F.; as certain species of bacteria are known not to live in temperatures exceeding 104° F. The temperature of the closed room, in which the cultivation of the bacteria takes place, is kept day and night at 60°·8 and 71°·6 F.

(3) *Comparative Chemical and Bacteriological Analyses of Unfiltered and Filtered Water* (Graphical Table II, Appendix).—From the Departmental Returns, the Author has deduced the comparative data and average results embodied in Tables II to VI, as follows:—

Table II.—Chemical Analyses of Unfiltered and Filtered Lake-Water, being the Mean of a Series of Analyses from Different Parts of the Lake.

	Parts per 1,000,000.	
	Unfiltered.	Filtered.
Dry residue	154·0	152·5
Glow residue	140·3	143·2
Organic matter	18·8	15·2
Ammonia	trace	slight trace
Albuminoid ammonia	0·039	0·023
Nitrous acid	0	0
Nitric acid	trace	trace
Chlorides	trace	trace
Sulphates	reaction	reaction
Hardness, English degrees	8·75	8·92

Inorganic Constituents.	Parts per 1,000,000.	
	Unfiltered.	Filtered.
Alkali (Na_2O)	2·5	2·5
Magnesia (MgO)	9·7	9·8
Lime (CaO)	61·6	62·3
Iron and alumina	1·2	2·0
Silica	3·4	4·0
Chlorine (Cl)	1·4	1·3
Nitric acid (N_2O_5)	1·5	1·5
Sulphuric acid (SO_3)	9·1	9·4
Carbonic acid, determined from hardness	50·3	51·0
Total mineral matter	140·7	143·8

This analysis shows that the hardness of the water increases about ½ degree by filtration.

TABLE III.—PRINCIPAL CHEMICAL CONSTITUENTS IN PARTS PER 1,000,000 AND NUMBER OF BACTERIA IN UNFILTERED LAKE-WATER AT VARYING DEPTHS OF INTAKE.

—	At 13 Feet.	At 39 Feet.	At 46 Feet.	At 52 Feet.
Organic matter	21·1	21·6	21·6	21·7
Ammonia	0·006	0·011	0·011	0·011
Albuminoid ammonia . . .	0·046	0·044	0·044	0·048
Bacteria per cubic centimetre	149	160	175	352

This Table shows that the quality of the water is not impaired by greater depth of intake up to a limit of 46 feet; whilst at 52 feet, the increased quantity of bacteria points to the water being affected by micro-organisms living at the bottom (56 feet).

TABLE IV.—PRINCIPAL CHEMICAL CONSTITUENTS IN PARTS PER 1,000,000, AND NUMBER OF BACTERIA IN UNFILTERED AND FILTERED LAKE-WATER AT THE FILTER-STATION, PUMPING-STATION, AND POINTS OF DISTRIBUTION, IN 1889.

—	Before Filtration.	After Filtration.	At Distribution.	Less after Filtration.
				Per cent.
Organic matter	18·2	14·5	14·8	20
Ammonia	0	0	0	0
Albuminoid ammonia . . .	0·034	0·020	0·021	40
Bacteria	175	17	27	90

TABLE V.—AVERAGE NUMBER OF BACTERIA FOR FOUR YEARS.

Per Cubic Centimetre . . {	Before Filtration.	After Filtration.	At Distribution.	Less after Filtration.
				Per cent.
1886	178	25	27	86
1887	239	18	39	93
1888	188	19	29	90
1889	175	17	27	90
Average . . .	195	20	31	90

The effect of filtration is seen from a glance at the two graphical Tables A and B, Appendix II, which give the chemical and bacteriological results for the year 1890, and the bacteria for the period of 4 years as above. These Tables, in conjunction with the above results, show that the filter-beds retain 90 per cent. of the bacteria; and also reduce the organic matter and albuminoid ammonia by 20 per cent. and 40 per cent. respectively; although, during distribution, there is again an insignificant increase, when the water occasionally remains at rest instead of circulating in the distributing-pipes.

TABLE VI.—LAKE-WATER AND SPRING-WATER COMPARED, 1889.

Chemical Constituents in Parts per 1,000,000.	Before Filtration.		After Filtration.	
	Spring Water.	Lake Water.	Spring Water.	Lake Water.
Organic matter	13·2	18·2	11·3	14·5
Ammonia	0	0	0	0
Albuminoid ammonia . . .	0·013	0·034	0·013	0·020
Bacteria per cubic centimetre	323	175	41	17
Hardness, French degrees .	33·0	12·5	33·0	12·75

This Table shows that, whilst the chemical quality of both waters is practically the same, the spring-water contains nearly double the number of bacteria contained by the lake-water, and that, therefore, the filtered lake-water is superior as potable water to that derived from the springs.

III. SELF-PURIFICATION OF THE RIVER LIMMAT.

The new drainage system of the town and suburbs of Zurich dates from the year 1883, and was constructed to utilize the collected sewage in irrigating a tract of about 300 acres of land situated about 2 miles below the town, specially acquired for that purpose by the Corporation at a cost of over £40,000. Owing, however, to local opposition, the irrigation was deferred; and, in the meantime, the sewage-main discharges into a collecting-well close to the left bank of the Limmat, at a point about 1,090 yards below the pumping-station of the waterworks: and thence discharges into the river by three 25-inch pipes, which are

laid obliquely to the course of the river, the outfall taking place in midstream, 66 feet from either bank. The average delivery of sewage is 4,400,000 gallons, the maximum being 11,000,000 gallons, per day; whilst the average flow of the Limmat, including the River Sihl, is 1,980,000,000 gallons per day; the sewage, therefore, represents about 0·2 per cent. of the average daily volume of the river. The pollution of the Limmat by this outfall naturally raised great objections on the part of the riparian population in the immediate vicinity; not only because it was likely to damage iron and timber structures and water-wheels by the action of ammonia and deposit of mud; but on account of the injury to be apprehended to the public health and pisciculture. The inquiry which was instituted into this matter demonstrated the fact of neither chlorides, sulphides, nitrogen, nor ammonia being present in any excessive quantity; and showed that the impure matter contained in the sewage is largely decomposed before it reaches the point of outfall. Subsequently, a series of bacteriological investigations were undertaken by the Hygienic Institute of Zurich,[1] with the view of ascertaining whether the changes which the Limmat water undergoes owing to the sewage mixing with it, renders it unfit for pisciculture and the domestic purposes for which it is used lower down the river.

The inquiry was conducted by weekly investigations extending from January to April, 1889; a season when the volume of the river is lower and more constant than at any other time of the year. Samples of the water were taken at different stations (ranging according to the velocity of the river on each day over a distance of about 10 miles), not simultaneously, but in succession; and were, within an hour or two after being taken, put under cultivation according to the bacteriological method already referred to. In the Appendix, Table III, the Author has worked out, extended, and arranged in an intelligible form the results of these investigations; together with the meteorological data, and the volumes and velocities of the river as far as they relate to the 10 days on which samples were taken at all the 9 stations in succession; deducing therefrom the average number of bacteria and rate of self-purification at each station, as the only satisfactory method of arriving at a reliable conclusion. From the Table referred to it will be seen: (1) That 96 per cent. of the precipitation takes place within 0·3 mile below the sewage outfall: (2) That within 6 miles of the sewage outfall, the number of

[1] Hygienic Institute, Zurich, Dr. C. Schlatter, 1890.

bacteria falls to the number immediately above that point: (3) That the greater the volume and velocity of the river, the slower is the rate of self-purification: (4) That, so far as concerns the sewage, the rate of self-purification is not influenced by meteorological changes.

The River Limmat, after its confluence with the Sihl, and below the Zurich waterworks, has a fairly uniform width of about 98 feet, and a depth of about $6\frac{1}{2}$ feet, its discharge being 317,850,000 cubic feet per day; hence its mean velocity is about 4 miles per hour. Its fall from Zurich to the well-known sulphur baths of Baden, a distance of 18 miles, is 10·5 feet per mile; and the time the water takes to travel from the outflow of the lake to Baden is about $5\frac{1}{2}$ hours. After passing the waterworks, the river only receives a few insignificant streams, which, although after rain they carry sand in suspension, do not materially affect the rate of self-purification of the river. Taking, therefore, the mean decrease of bacteria between two stations at 40 per cent. within 6 miles, it follows that within an additional distance of 6 miles, the process of self-purification will be complete; *i.e.*, the bacteria will be reduced to the normal number of the lake-water, or about 170 per cent. And that this is actually the case, is attested by the fact that at Baden the Limmat water is freely used for domestic purposes, and that fish live in it in abundance. These considerations therefore lead to the conclusion that, under the conditions described, and provided there are no intermediate sources of pollution, a river such as the Limmat, flowing at the mean velocity of about 4 miles per hour, will purify itself within distance of about 16 miles from the point of pollution.

APPENDIX.

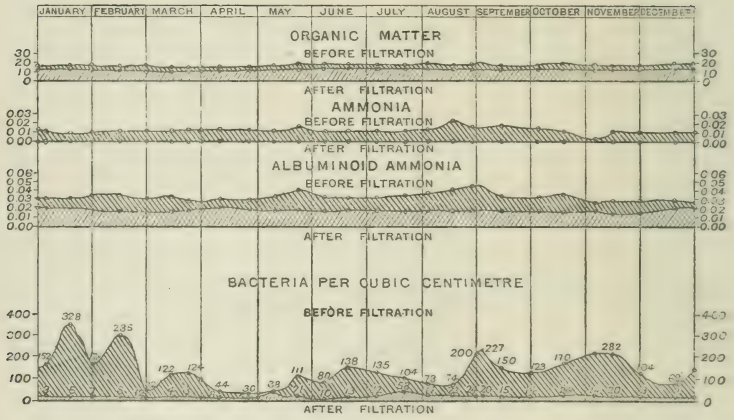
Table I.—Roofed and Open Filter-Beds.

Cost of Construction and Working and the Action of Filter-beds.

	Three Roofed Filter-beds. Cost of Filtering Surface. Per Square Yard.	Two Open Filter-beds. Cost of Filtering Surface. Per Square Yard.
(1) Cost of construction—	£ s. d.	£ s. d.
Land, intake, and mains	5 8 2	5 8 2
Filter-beds and wells	3 1 0	1 19 5
Conduits, outer wells, and sand depot	0 17 7	0 17 7
Total	9 6 9	8 5 2
	Per 1,000,000 Gallons.	Per 1,000,000 Gallons.
(2) Cost of working—	Pence.	Pence.
Superintendence	9·22	11·22
Cleansing and replenishing sand	10·15	16·65
Breaking ice	..	2·07
Renewal of filtering-strata	10·19	18·88
Maintenance, intake, and mains	4·50	5·25
Repairs and sundries	2·00	2·30
	36·55	56·37
6 per cent. interest and sinking-fund	327·45	347·63
Total	£1 12 8	£1 13 7
	Roofed.	Open.
(3) Action of filter-beds—		
Total filtering-surface	sq. yds. 2,410	sq. yds. 1,663
Filtering surface per filter-bed	,, 803	,, 832
Total delivery per annum average	galls. 984,793,000	galls. 565,878,000
,, ,, per filter-bed per annum average	,, 328,264,000	,, 188,626,000
,, ,, per unit of filtering-surface per annum . . . average	,, 488,400	,, 406,260
One filter-bed requires renewal of material	after 3 years 4 months.	after 2 years 5 months.
Emptying, cleansing, renewal, and refilling requires	30 days.	35 days.
Filtration to waste	11 ,,	20 ,,
Total of renewal period	41 ,,	55 ,,

TABLE II (GRAPHICAL).

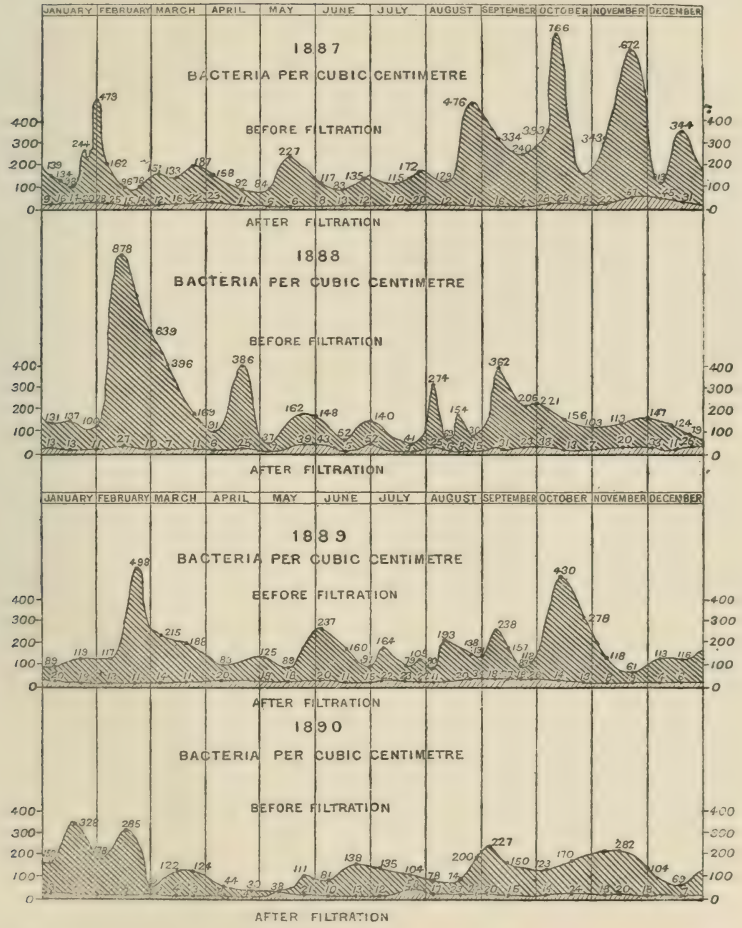
A.



LAKE-WATER BEFORE AND AFTER FILTRATION; CHEMICAL AND BACTERIOLOGICAL TABLE, 1890; INTAKE IN LAKE 46 FEET BELOW MEAN WATER-LEVEL.

TABLE II (GRAPHICAL).

B.



LAKE-WATER BEFORE AND AFTER FILTRATION; COMPARATIVE BACTERIOLOGICAL TABLE, 1887–90; INTAKE IN LAKE 46 FEET BELOW MEAN WATER-LEVEL.

TABLE III.—SELF-PURIFICATION OF

1890.	Mean Temperature in Degrees Centigrade.	Rain or Snow.	Sectional Area.	Volume of Flow per second.	Velocity per second.
	°		Square Feet.	Cubic Feet.	Feet.
6 February	− 2·8	Snow	581	883	1·47
13 ,,	−10·7	,,	597	954	1·61
18 ,,	+ 4·7	Thaw	646	1,236	1·90
20 ,,	+ 1·3	Rain	624	1,130	1·805
25 ,,	− 4·7	Snow	646	1,201	1·93
27 ,,	− 5·8	,,	646	1,165	1·805
4 March	− 2·8	,,	592	918	1·57
6 March	− 2·8	,,	603	989	1·64
26 April	+ 6·3	Rain	797	3,249	4·07
30 ,,	+11·6	,,	904	4,414	4·87
Average	− 3·1	..	664	1,614	2·28
Increase or decrease per cent.	..	..	..	..	..
Distance between stations	..	..	..	..	..
Distances from Station 1	..	..	..	..	..

Distance from Lake.	Distance from Sewage Outfall.	SELF-
Miles.	Miles.	
13·5	6·21	at station 9
15·5	7·46	,, ,, 10
17·5	8·70	,, ,, 11
19·5	9·94	,, ,, 12
21·5	11·18	,, ,, 13
23·5	12·42	,, ,, 14

At station 14, 12 miles from sewage-outfall

THE RIVER LIMMAT.

Number of Bacteria per Cubic Centimetre.									Decrease between Stations 3 and 4.
Outflow from Lake.	Mill.	Outfall of Sewage.	Mill.	Ferry.	Bridge.	Bridge.	Ferry.	Ferry Dictikon.	
Station 1.	Station 2.	Station 3.	Station 4.	Station 5.	Station 6.	Station 7.	Station 8.	Station 9.	
									Per cent.
117	1,290	966,670	25,270	15,060	18,270	15,050	2,220	2,000	98·0
244	200	206,670	9,650	5,820	3,830	1,430	900	800	96·0
371	3,350	113,930	5,480	2,300	2,350	400	1,050	1,700	96·0
498	6,870	329,290	53,470	51,140	6,370	2,950	2,470	1,080	84·0
300	1,250	60,810	1,290	1,540	860	800	1,980	510	89·0
100	160	56,130	340	440	150	250	250	250	99·4
200	1,020	397,760	18,650	9,840	7,250	7,500	3,600	3,900	95·0
213	1,220	764,090	28,700	16,160	14,270	5,700	1,940	3,130	97·0
83	1,050	37,580	2,220	2,640	4,000	2,540	5,100	5,100	94·0
125	1,000	33,770	3,000	4,380	1,650	5,560	3,950	3,550	91·0
225	1,731	296,670	12,870	10,892	5,902	4,218	2,346	2,100	..
..	+770 / 1 : 7·7	+17,138 / 1 : 171·4	−96	−15	−46	−28	−45	−10	..
		Mean decrease between two stations = 40 per cent.							
..	9,843 feet	1,640 feet	1,640 feet	1,640 feet	3,281 feet	13,124 feet	1,640 feet	11,483 feet	44,292 feet
..	1·86 mile	2·175 miles	2·485 miles	2·796 miles	3·417 miles	5·903 miles	6·214 miles	8·078 miles	8·078 miles
		$\frac{2,100 + 100}{296,670} = 0·7$; 100 − 0·7 = 99·3 per cent.; decrease 99·3 per cent. in 6 miles.							

PURIFICATION IN 12 MILES.

bacteria 2,100 per cubic centimetre.
,, 1,260 ,, ,, − 40 per cent.
,, 756 ,, ,, − 40 ,,
,, 452 ,, ,, − 40 ,,
,, 272 ,, ,, − 40 ,,
,, 164 ,, ,, − 40 ,,
(Bacteria at outflow from lake = 225.)

the water is as pure as at its issue from the lake

(Paper No. 2660.)

"Relative Powers of Lighthouse Lenses."

By Alan Brebner, B.Sc., Assoc. M. Inst. C.E.

The purpose of this Paper is to describe a novel method of determining the relative values of lighthouse lenses of different form, size, or composition, in condensing the light of a flame of given dimensions. It may be said that in general such lenses are designed to convert into a single horizontal beam of parallel rays all the rays which, issuing from their principal foci, fall on their inner surfaces. This can be done approximately, but not absolutely, since the curved lines of the generating profiles of the prisms are made circular instead of being formed to the curve prescribed by theory. The error resulting from this amounts to a deviation of certain focal rays by a few minutes from the direction of the parallelized beam, and this error will be neglected in the present Paper. On the other hand, all lighthouse illuminants have a certain volume, so that most of the rays from them are ex-focal, and, after leaving the lens, diverge more or less from the direction of the axis of the beam. The amount of this divergence increases with the ex-focality, but is also affected by the form of the lens and by its distance from the focus. Let Fig. 1, Plate 10, represent the horizonal focal half-section of a plano-convex stepped lens with a lamp-flame at its focus, and the elevation of one quarter of the lens. If r be the radius of the flame, and d the focal distance of a ray falling from F on the middle point of any element, then the angle of incidence of an extreme ex-focal ray is evidently greater or less than the angle of incidence of the focal ray on the same point by $\sin^{-1}\frac{r}{d}$, therefore, since this angle ought never to be very large, by an angle varying inversely as the focal distance. It might be expected that the angle of divergence at exit from the lens would also diminish as the distance d increased. But, on the contrary, as stated by Mr. J. T. Chance,[1] it increases.

In order to calculate the amount of this increase in the case of a particular lens, the Author has made use of his design of the

[1] Minutes of Proceedings Inst. C.E., vol. xxvi. p. 486.

profiles (Nos. 1 to 10, Fig. 1), according to which the hyperradiant lens of 1·33 metre focal length, tested at the South Foreland in 1885, was made, and of two others (Nos. 11 and 12, Fig. 1), which were designed by him for Messrs. F. Barbier and Co. He has assumed a radius of flame $r = 46{\cdot}55$ millimetres, for which the flame subtends at C an angle of 4°, and has calculated the angles of divergence of emergent rays corresponding to internal angles formed by rays tangential to the flame and incident at the limiting points of successive prisms. He has then considered the mean between the divergences corresponding, for example, to the outer limits of elements 2 and 3, as the mean divergence for element 3, and so on. The amounts of the mean divergence at emergence thus obtained are given in column 7 of Table I. An example of the calculation of this divergence in the plane of a generating profile will be found in the Appendix.

As shown in Table I, column 7, the mean divergence in the plane of a generating section, at present supposed to be the horizontal focal plane, is, for the central lens, less than the angle subtended at its centre C by the diameter of the flame, or, what is practically equivalent, less than $2 \sin^{-1} \frac{r}{d}$ —this angle being 4°. This is exceptional, however, and peculiar to the central lens; for all the other elements it will be seen that the mean divergence exceeds the central internal angle of 4°. It will be convenient to refer to the angle subtended by the diameter of the flame in the focal plane at the centre of the inside of the central lens, as the "unit-angle" for the given combination of lens and lamp.

Let it be supposed that the flame at F is spherical, its centre being at the principal focus F. The height of the flame is therefore $2r$. Now it is required to find the mean vertical divergence due to this height $2r$, for each prism in succession along the horizontal focal plane. This divergence, it will be observed, is at right-angles to that indicated for successive prisms in column 7 of Table I, or at right-angles to the generating section. Again, let a vertical focal plane through FC be considered. The flame subtends at C, in the horizontal focal plane, an angle equal to $2 \sin^{-1} \frac{r}{d}$. Suppose the generating section of Fig. 1 to be turned about the axis FC into a vertical position. It is required to find what law the horizontal divergence of the emergent angle corresponding to $t\ C_n\ t_1$ follows, where C_n is any internal point of the lens in a vertical plane upon CF. It may be here remarked

that the late Mr. Allard[1] assumes that the horizontal divergence at any point of a lens diminishes as the focal distance of this point increases. It has, however, been shown that this is not the case in the horizontal focal plane, where, on the contrary, the horizontal divergence increases with focal distance. To ascertain how the horizontal divergence varies from point to point of a lens in the vertical axial focal plane, two examples have been worked out in the manner shown in detail in the Appendix. In these examples, the points for which the horizontal divergence at exit from the lens was calculated were the uppermost inner points of the first and the twelfth prisms, the points S_1 and S_{12} of Fig. 1, when the section shown is supposed turned about FC into the vertical plane. In both cases, the horizontal divergence at exit was found to bear to the unit-angle the inverse ratio of the focal distances of the points of incidence, and the horizontal divergences at exit of rays incident at S_1 and S_{12} were found to be inversely proportional to the focal distances FS_1 and FS_{12}.

Now, let it be supposed for a moment that the flame at the focus is a sphere. Then, since it has been proved that in the plane of a generating section, the divergence increases with the focal distance, and that in a plane at right-angles to the former, it varies inversely as the focal distance, it is clear that if the whole lens be internally masked, excepting one point or small area anywhere on its surface, and the pencil of rays that emerges from it be intercepted on a screen, an inverted and distorted image of the spherical flame will be obtained. Suppose the screen distant from the lens by a distance equal to the principal focal length. Then a diameter of the flame in the axial focal plane through the unmasked point will be elongated on the image, whilst a diameter at right-angles to the former will be shortened. The image, therefore, will be of an elliptical or nearly elliptical form[2] (*Fig. 1*), the major axis a being greater than the diameter

[1] Mémoire sur l'Intensité et la Portée des Phares, p. 36.

[2] In the Industrial Museum at Edinburgh, the lens, whose dioptric profiles are shown in Fig. 1, has been installed with a red spherical ball at its focus. If an observer looks at the red ball first through the centre of the lens it will appear round, but, on moving the eye gradually in any radial straight line from the centre across successive zones, the ball will appear to assume an oval form, being gradually elongated in the direction followed by the eye, and simultaneously shortened at right-angles to that direction. The effect that would be produced by a spherical lens, like that of Fair Isle, would be similar, but much more pronounced—the elongation for the extreme zone being 67 per cent. greater than for the corresponding plano-convex zone, as the figures 249 (Table I, column 7) and 417 (Table II, column 5) show.

of the flame, the minor axis b less, and the area of the image proportional to the product ab. Now any proper combination of lighthouse-lamp and lens involves angles of divergence not greater than about 12°. Suppose the unmasked point be E, neglecting the thickness of the lens, and supposing the distance of the screen equal to d, the maximum divergence of emitted light equal to A, and the minimum equal to B,

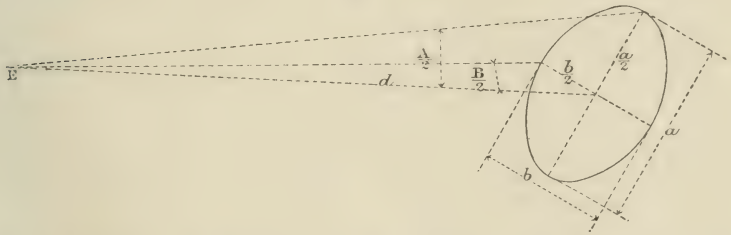
Then $$\frac{a}{2d} = \tan\frac{A}{2}, \text{ and } \frac{b}{2d} = \tan\frac{B}{2};$$

therefore $$ab = 4d^2 \tan\frac{A}{2}\tan\frac{B}{2};$$

and since neither $\frac{A}{2}$ nor $\frac{B}{2}$ should be greater than about 6°, the angles $\frac{A}{2}$ and $\frac{B}{2}$ may be substituted for their tangents;

hence $$ab = 4d^2\frac{A}{2}\times\frac{B}{2} = d^2\,A\,B;$$

Fig. 1.



also, d being a constant quantity equal to the principal focal length, ab is seen to vary as A B. The intensity of illumination of the image varies as $\frac{1}{ab}$, or as $\frac{1}{A\,B}$; that is, inversely as the product of the divergences in the plane of a generating section, and at right-angles to this plane, respectively.

The whole beam of light emitted by a lens with a lamp at its focus consists of the sum of the pencils of rays which pass through all the points of its inner surface. If these pencils were all similar, the relative values of different lenses acting on equal spherical flames would be directly proportional to the portions of spheres round their foci intercepted by them, and inversely proportional to the products of the divergences in planes of generating sections and those at right-angles to such planes. The flame is at present considered both spherical and homogeneous, so that its intensity

is the same in every direction. A clear idea of what takes place for actual lamp-flames is thus arrived at more easily than if the question were directly studied for these flames. Since, however, the elliptical image of the flame, obtained on a screen as described, varies in size and form for different unmasked points from the centre of the lens outwards, it is necessary to find the mean divergences in the plane of a generating section and at right-angles to the same, first for each dioptric element, and next for the entire lens under consideration. Column 7, Table I, gives for the lens and flame of Fig. 1, Plate 10, the mean divergence in any plane of the generating section.

The mean divergence in a plane at right-angles to any plane of the generating section has next to be found. What is ultimately wanted is the mean divergence of the whole lens in this plane; so that, instead of determining the mean divergence for each prism, it will suffice to determine quantities proportional to these divergences. Now the divergence at the middle point of the inner side of each profile may be taken as the mean divergence of such profile. This divergence has been proved inversely proportional to the focal distance,[1] and is, therefore, directly proportional to the cosine of the angle which the focal ray falling on the point considered makes with the horizontal axis of the lens. Column 4, Table I, gives the cosines for the middle ray on each prism. These cosines show what fraction of the unit-angle, as defined above, is the divergence at right-angles to the generating section of each pencil of rays passing out through the middle points of successive prisms.[2] To obtain the mean divergence for the whole lens, whether in any plane of the generating section or at right-angles to such plane, the portion of the emitted sphere of light falling on each lenticular ring must be determined. The lens shown in Figs. 1 is supposed to be round in elevation, so that each element of the lens forms a complete ring. In the case, however, of a lens in which there are segments of rings to be considered, as frequently occurs, the amount of light falling on any such segment will bear to the amount that would have fallen on an entire ring the ratio of the angle subtended by it at the centre of the lens to 360°. Considering now the lens at present under treatment, column 2, Table I, gives the outer limiting angles of successive elements. Suppose the focus surrounded by a sphere

[1] Appendix.

[2] Since Table I was compiled, column 11, showing actual angles to which the figures of column 4 are proportional, has been added for the sake of comparing directly corresponding maximum and minimum angles of divergence.

of radius unity, then the amount of the sphere intercepted by element No. 1 is proportional to the versed sine of its limiting angle, that which is intercepted by No. 2 is proportional to the versed sine of limiting angle 2 minus the versed sine of limiting angle 1, and so on. Column 5 gives the versed sines for successive limiting angles, and column 6 the heights of successive spherical zones corresponding to successive elements, which are proportional to the amounts of light intercepted by successive elements. Columns 8 and 9 give the products of corresponding figures of columns 6 and 7 and of columns 6 and 4 respectively. The total of column 8 divided by that of column 6 gives the mean divergence for the whole lens in the plane of any generating section. The total of column 9 divided by that of column 6 gives a fraction which bears the same ratio to unity as does the mean divergence of the whole lens at right-angles to the plane of such generating section to the corresponding unit-angle at the centre of the lens. The mean divergence, then, for the entire lens shown in half-section in Fig. 1, with a spherical illuminant of radius equal to 46·55 millimetres at the focus, in the plane of any generating section, is $\frac{37\cdot4086}{0\cdot15164} = 246\cdot7'$, and the mean divergence at right-angles to such plane is $\frac{0\cdot140194}{0\cdot15164}$, or 0·9245 of the unit-angle, that is, $0\cdot9245 \times 240' = 221\cdot9'$. The inclination of any bounding ray of this lens to the horizontal axis is 31° 58′.

It is now proposed to examine what happens in the case of a lens made internally spherical, as proposed by Mr. Charles A. Stevenson, M. Inst. C.E. Fig. 3, Plate 10, shows the profiles designed by the Author for Messrs. F. Barbier and Co., for the construction of an apparatus in four groups of double panels giving double flashes, as ordered from that firm by Messrs. Stevenson of Edinburgh, and subsequently erected at the Fair Isle, between Orkney and Shetland. Mr. C. A. Stevenson, to whom the undetailed design is due, has carried the spherical portion of the refractor out to about 28° 22′ from the axis, completing the lens by a portion of the usual plano-convex lens from 28° 45′ to 38°. The Figure shows a single panel of the apparatus in horizontal focal section and in elevation. Reference is at once made to this apparatus because it was the first constructed containing the form of internally spherical lens proposed by Mr. C. A. Stevenson. It will, however, be more convenient to treat in the first place another sphero-convex lens designed by the Author for Messrs. F. Barbier and Co., shown in Figs. 2, Plate 10,

TABLE I.

1 Title of Element.	2 Limiting Angle of Element.	3 Middle Angle of Element.	4 Cosine of Middle Angle, proportional to Divergence at Right Angles to a Generating Section.	5 Versed Sine of Limiting Angle.	6 [Height of Zone of Sphere, Radius 1, Corresponding to each Element.	7 Mean Divergence in a Plane of the Generating Section.	8 Product of Figures of Columns 6 and 7.	9 Product of Figures of Columns 6 and 4.	10 Multiplier of Figures of Columns 6, 8, and 9, for Comparison with Fair Isle Lens.	11 Mean Divergence at Right Angles to a Plane of the Generating Section.
	° ′	° ′				′				′
P – 1 . . .	8 8	4 4	0·99748	0·01006	0·01006	236	2·3742	0·010035	$\frac{300}{360}$	239
P – 2 . . .	11 53	10 0	0·98481	0·02143	0·01137	242	2·7516	0·011197	$\frac{245}{360}$	236
P – 3 . . .	14 59	13 26	0·97264	0·03400	0·01257	243	3·0546	0·012226	$\frac{225}{360}$	233
P – 4 . . .	17 38	16 18	0·95981	0·04699	0·01299	244	3·1696	0·012468	$\frac{216}{360}$	230
P – 5 . . .	19 58	18 48	0·94665	0·06011	0·01312	246	3·2275	0·012420	$\frac{212}{360}$	227
P – 6 . . .	22 2	21 0	0·93358	0·07303	0·01292	247	3·1913	0·012062	$\frac{208}{360}$	224
P – 7 . . .	23 56	22 59	0·92062	0·08598	0·01295	248	3·2116	0·011922	$\frac{205}{360}$	221
P – 8 . . .	25 42	24 49	0·90766	0·09892	0·01294	249	3·2220	0·011745	$\frac{203}{360}$	218
P – 9 . . .	27 23	26 32	0·89467	0·11205	0·01313	249	3·2693	0·011747	$\frac{201}{360}$	215
P – 10 . . .	29 0	28 12	0·88130	0·12538	0·01333	250	3·3325	0·011748	..	212
P – 11 . . .	30 31	29 45	0·86820	0·13852	0·01314	251	3·2982	0·011408	..	208
P – 12 . . .	31 58	31 15	0·85491	0·15164	0·01312	252	3·3062	0·011216	..	205
Totals . .	..	..	..	..	0·15164	..	37·4086	0·140194	..	..

which forms part of a lens of 2 metres focal length proposed to be supplied to Edmundson's Furnishing and Engineering Company in order to utilize the large gas-burners of Mr. Wigham. Figs. 2 show in horizontal focal section and in elevation one complete panel subtending 90° horizontally and 64° vertically. The outer limiting ray of the spherical portion of the lens has an inclination of 32° 18′ to the axis; in elevation this spherical portion is round, and it is very suitable for comparison with the plane lens of Figs. 1.

Let a spherical flame of 70 millimetres radius with its centre at the focus be supposed to be the illuminant. The angle subtended by the flame at the centre of the lens is $2 \sin^{-1} \frac{70}{2,000}$, $= 4°$, the same unit-angle as for the combination of plane lens and lamp considered above. Table II refers to this spherical lens. The

TABLE II.

1 Title of Element.	2 Limiting Angle of Element.	3 Mean Divergence at Right Angles to a Plane of the Generating Section.	4 Height of Zone of Sphere, Radius 2,006 Millimetres, corresponding to each Element.	5 Mean Divergence in a Plane of the Generating Section.	6 Product of Figures of Columns 4 and 5.	7 Multiplier of Figures of Columns 4 and 6 for Fair Isle Lens.
	° ′	′		′		
S — 1	7 3	240	9·0	244	2,196·0	$\frac{307}{360}$
S — 2	10 20	240	16·6	256	4,249·6	$\frac{248}{360}$
S — 3	13 8	240	20·0	268	5,360·0	$\frac{227}{360}$
S — 4	15 37	240	22·5	282	6,345·0	$\frac{216}{360}$
S — 5	17 46	240	21·6	298	6,436·8	$\frac{211}{360}$
S — 6	19 51	240	23·5	315	7,402·5	$\frac{207}{360}$
S — 7	21 50	240	24·7	337	8,323·9	$\frac{205}{360}$
S — 8	23 43	240	25·5	360	9,180·0	$\frac{203}{360}$
S — 9	25 33	240	26·7	386	10,306·0	$\frac{201}{360}$
S — 10	27 20	240	27·9	417	11,634·2	$\frac{200}{360}$
S — 11	29 3	240	28·4	454	12,893·6	..
S — 12	30 42	240	28·8	498	14,342·4	..
S — 13	32 18	240	23·0	551	12,673·0	..
Totals	..	..	298·2	..	111,343·0	..

mean divergences of successive elements in a plane of the generating section are given in column 5. These, as well as those of column 7, Table I, are determined for a refractive index

of 1·53, and neglect chromatic dispersion. The rapid increase of divergence in passing down column 5 will be noticed. The divergences at right-angles to those of column 5 are shown in column 3, and, being inversely proportional to the focal distance, which is constant, they are also constant, and equal to the unit-angle of 240′. In this case the relative quantities of light intercepted by each prism are given in terms of the heights of corresponding zones of a sphere of 2,006 millimetres radius, and are stated in column 4. The mean divergence of the whole lens in a plane of the generating section is the total of column 6 divided by the total of column 4, or $\frac{111,343}{298\cdot2} = 373\cdot38'$. The mean divergence of the whole lens at right-angles to the same plane is 240′.

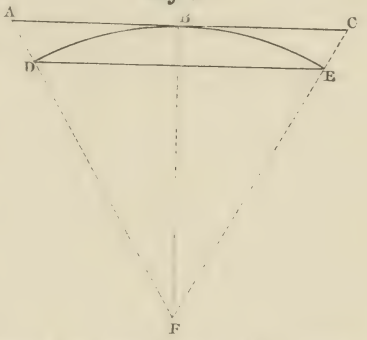
In the case of the two plane and spherical lenses considered, it will be observed that although the principal focal lengths differ, being respectively 1·33 metre and 2 metres, the proportion of flame-diameter to focal distance has been chosen the same, so that the coefficient of either combination is the same as would hold if the lens of one of them were of equal principal focal length to that of the lens of the other combination, and had a like flame at its focus. Therefore the comparison is in reality between the efficiency of a plane lens and that of a spherical lens of the same principal focal length, as represented by ABC and DBE respectively of *Fig. 2*, and intercepting the same portion of the sphere of light issuing from similar and equal flames. If P stands for the coefficient of the plane lens, and S for that of the spherical lens, then $\frac{P}{S} = \frac{373\cdot38 \times 240}{246\cdot7 \times 221\cdot9} = 1\cdot637$, or the coefficient of the plane lens is in this case 63·7 per cent. greater than that of the spherical.

Suppose, however, that the lenses form panels of a revolving light apparatus, then the extreme radius[1] FA, *Fig. 2*, of the plane lens ABC would be greater than FD, that of the spherical lens DBE, by the length AD, and would necessitate a larger lantern. It is, therefore, important to compare the coefficient of a plane lens such as DE, Fig. 2, Plate 10, with that of the spherical lens DBE, of equal maximum radius FD. The principal focal length FC of this plane lens is 1·69 metre. Supposing the radius of the flame

[1] To avoid confusion, it may be well to premise that "radius," both here and as it will occur again in a similar connection in the sequel, means greatest focal distance in the horizontal focal plane.

the same as in the case of the 2-metre spherical lens, or 70 millimetres, then the angle subtended by the flame at C is $2 \sin^{-1} \frac{70}{1{,}690} = 285'$, which is the unit-angle of the combination of lens and lamp considered. Now with a unit-angle of 240′ were found mean divergences, for a plane lens, in the direction of a generating section, 246·7′, and at right-angles to the same section, 221·9′; therefore, for the lens of 1·69 metre focal length, these angles have to be multiplied by $\frac{285}{240}$, and the coefficient of the lens DCE is to that of the lens DBE, Fig. 2, in the ratio $\frac{373{\cdot}38 \times 240}{246{\cdot}7 \times 221{\cdot}9 \times \left(\frac{285}{240}\right)^2} = 1{\cdot}161$. Thus the coefficient of a plane lens subtending an angle of 64° in every axial plane at the focus is 16 per cent. greater than that of the corresponding spherical lens of the same maximum radius, or that can be used with the same catadioptric prisms.

Fig. 2.



Referring again to the lens proposed by Mr. C. A. Stevenson, Fig. 3, Plate 10, it is required to determine whether the spherical lens limited to an angle of 28° 22′ from the axis be not better than the corresponding plane lens of equal maximum radius and of 1·18 metre focal length. As may be seen from the elevation of the Fair Isle lens, which is that shown in Fig. 3, no one of the dioptric rings is complete, and there is relatively less of each ring the further it is removed from the centre. This must not be neglected in comparing it with the corresponding plane lens. Evidently there is no necessity for repeating, in the case of every different focal length of lens, the calculations made for plane and spherical lenses epitomised in Tables I and II. From what precedes, it may be seen that the further the spherical lens is carried out beyond its axis, the more disadvantageous it becomes, on account of the rapid increase of divergence in planes of the generating section. If then, the first 10 elements (S − 1 to S − 10, Table II) of the 2-metre spherical lens, extending to 27° 20′ from the axis, be compared with the first 9 elements (P − 1 to P − 9, Table I) of the 1·33-metre plane lens extending

to 27° 23′, a relative efficiency more favourable to the spherical lens will be obtained than if 28° 22′, the limiting angle of the Fair Isle lens, were that of the two lenses compared. In order to allow for the form of the Fair Isle lens, in which a larger portion of each ring comes into play the nearer it is to the centre, the figures of columns 6, 8 and 9, Table I, Nos. 1 to 9 must be multiplied by those of column 10, and the figures of columns 4 and 6, Table II, Nos. 1 to 10 must be multiplied by those of column 7. Proceeding as before, the mean divergence in a plane of the generating section of elements P − 1 to P − 9, Table I, is found to be 244·73′ for a unit-angle of 240′; and the mean divergence at right-angles to a plane of the generating section is found to be 0·94771 of the unit-angle. Let the diameter of the spherical flame be 130 millimetres, or that of the 6-wick burner, which is probably the one actually used with the Fair Isle apparatus: then, the principal focal length of the corresponding plane lens being 1,180 millimetres, the unit-angle is $2 \sin^{-1} \frac{65}{1,180} = 379'$. Hence, the mean divergence in a plane of the generating section is $\frac{379}{240} \times 244{\cdot}73' = 386{\cdot}46'$, and the mean divergence at right-angles to such a plane is $0{\cdot}94771 \times 379' = 359{\cdot}2'$; or, for this combination, the product of maximum and minimum divergence $= 386{\cdot}46 \times 359{\cdot}2$. Next, multiplying the figures of columns 4 and 6 for S − 1 to S − 10, Table II, by those of column 7, and dividing the sum of the latter products by the sum of the former, the mean divergence in a plane of the generating section for these 10 elements is found to be 323·6′, corresponding to a unit-angle of 240′. The mean divergence at right-angles to such a plane is the same as the unit-angle. Now the unit-angle of the Fair Isle spherical lens for a flame of 130 millimetres diameter is $2 \sin^{-1} \frac{65}{1,330} = 336'$; and the mean divergence in a plane of the generating section is $\frac{336}{240} \times 323{\cdot}6' = 453{\cdot}04'$, so that the product of maximum and minimum divergence for this combination is $453{\cdot}04 \times 336$. The efficiency of the lenses being in the inverse ratio of the products of their greatest and least divergences, it follows that in this case

$$\frac{\text{efficiency of plane lens}}{\text{efficiency of spherical lens}} = \frac{453{\cdot}04 \times 336}{386{\cdot}46 \times 359{\cdot}2} = 1{\cdot}0966;$$

or that the plane lens is 9·66 per cent. better than, giving a beam

9·66 per cent. more intense than, the spherical lens of equal maximum radius.

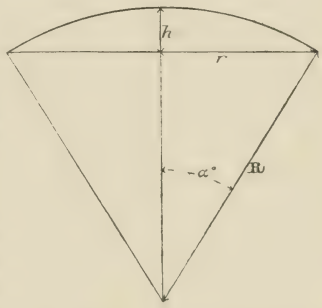
A similar calculation made for complete lenses, plane and spherical, carried to 27° 20′ beyond the axis, gives a superiority of 11·23 per cent. to the plane lens.

In the case of plane and spherical lenses of equal maximum radii extending 23° 50′, 17° 42′ and 7° 30′ beyond the axis, the superiority of the plane lens has been found to be respectively 7·95, 5·32, and 2 per cent. above the spherical.

Hence, although the superiority of the plane lens gradually diminishes until the two forms nearly coincide, it is maintained throughout; so that the spherical lens is in no case so efficient as the plane lens of equal maximum radius.

For a complete statement of the relative values of any forms of lens, several features, in addition to the divergences they cause, must be considered. These are, cost, loss of light by absorption in the glass, losses by superficial reflection at entrance and exit, and chromatic dispersion. The sequel will, however, show that a plano-convex lens has an advantage over a sphero-convex lens in respect of all these factors, except perhaps that of loss by superficial reflection, in which the sphero-convex lens has, possibly, a slight advantage.

Fig. 3.



For equal maximum focal distances, the cost of the two forms of lens may be taken to be proportional to the internal surfaces—plane and spherical. For lenses carried to $\alpha°$ (*Fig. 3*) beyond the axis all round, r being the radius of the plane lens, R the radius of the sphere of the spherical lens, or maximum focal distance of either lens, h the height of the spherical zone; the ratio of the plane surface to the spherical surface is—

$$\frac{\pi r^2}{2\pi R h} = \frac{R^2 \sin^2 \alpha}{2 R h} = \frac{R \sin^2 \alpha}{2 (R - R \cos \alpha)} = \frac{1 + \cos \alpha}{2}.$$

Substituting the values of α for lenses compared above, namely, 32°, 28° 22′, 23° 50′, 17° 42′, 7° 30′ in the formula, the following ratios of area of plane to area of spherical lens are obtained, namely, 0·924, 0·94, 0·9574, 0·9763 and 0·9957 respectively. Hence the plane lenses, which surpass the spherical in efficiency

by 16, 11·23, 7·95, 5·32 and 2 per cent., have also the advantage of costing less by 7·6, 6, 4·26, 2·37, and 0·4 per cent. respectively.

With regard to losses by absorption, any slight difference there may be is in favour of the plano-convex lens, since the sphero-convex lens of equal maximum focal length involves greater thicknesses of glass.

With regard to losses by superficial reflection, further experiments are required before the question can be accurately treated. This the Author will endeavour to explain, and for this purpose he would invite consideration of Tables III and IV.

Table III refers in particular to the lens of Fig. 1, Plate 10, taken as a type of plano-convex lenses in general. Table IV refers in particular to the lens of Fig. 2, taken as a type of sphero-convex lenses in general. In both Tables, α, β, γ, δ represent respectively angles of external incidence of limiting rays on the inner surface, corresponding angles of refraction, corresponding angles of internal incidence on the outer surface, and corresponding angles of emergence. In Table III $\alpha - \beta$ and $\delta - \gamma$ show the angles of deviation by refraction at surfaces of entrance and of exit respectively. In Table IV $\delta - \gamma$ shows the total deviation effected in the spherical lens at the surface of exit alone, and at the same time the inclination of successive limiting rays of elements S − 1 to S − 13, to the axis of the lens.

In estimating losses of light by superficial reflection in the case of lighthouse lenses, it has been the custom to use coefficients given by Mr. Allard in the work previously referred to. It is a matter for regret that he has not indicated how they were determined. One peculiarity they have is that they do not refer to losses at single surfaces, but include both the losses at the surfaces of entrance and of exit. If the angles of incidence of limiting rays of elements P − 1 to P − 12, Fig. 1, Plate 10, namely, angles α of Table III, be compared with the corresponding angles of emergence, namely, angles δ of the same Table, it will be seen that the latter are 58 per cent. to 85 per cent. greater than the former. Hence, inasmuch as losses due to superficial reflection at entrance and at exit are probably equal for equal angles of incidence and of emergence, the portions of the combined losses given by Mr. Allard, which are occasioned at emergence, must be considerably greater than the complementary portions occasioned at entrance. What the actual amounts of these portions are, however, can only, it seems, be determined by experiments specially devised for this purpose. If, again, the

angles of incidence and of emergence of the limiting rays of elements S − 1 to S − 13, Fig. 2, namely, angles α and δ of

Table III.

—	α	β	γ	δ	$\alpha - \beta$	$\delta - \gamma$
	° ′	° ′	° ′	° ′	° ′	° ′
P − 1	8 8	5 18	9 49	15 7	2 50	5 18
P − 2	11 53	7 44	14 2	21 46	4 9	7 44
P − 3	14 59	9 44	17 14	26 58	5 15	9 44
P − 4	17 38	11 26	19 50	31 16	6 12	11 26
P − 5	19 58	12 54	21 54	34 48	7 4	12 54
P − 6	22 2	14 12	23 38	37 50	7 50	14 12
P − 7	23 56	15 23	25 7	40 30	8 33	15 23
P − 8	25 42	16 28	26 25	42 53	9 14	16 28
P − 9	27 23	17 30	27 34	45 4	9 53	17 30
P − 10	29 0	18 28	28 35	47 3	10 32	18 28
P − 11	30 31	19 23	29 30	48 53	11 8	19 23
P − 12	31 58	20 15	30 20	50 35	11 43	20 15

Table IV.

——	α	β	γ	δ	$\delta - \gamma$
	° ′	° ′	° ′	° ′	° ′
S − 1	0 0	0 0	12 52	19 55	7 3
S − 2	0 0	0 0	18 11	28 31	10 20
S − 3	0 0	0 0	22 14	35 22	13 8
S − 4	0 0	0 0	25 24	41 1	15 37
S − 5	0 0	0 0	27 50	45 36	17 46
S − 6	0 0	0 0	29 57	49 48	19 51
S − 7	0 0	0 0	31 43	53 33	21 50
S − 8	0 0	0 0	33 12	56 55	23 43
S − 9	0 0	0 0	34 29	60 2	25 33
S − 10	0 0	0 0	35 35	62 55	27 20
S − 11	0 0	0 0	36 30	65 33	29 3
S − 12	0 0	0 0	37 18	68 0	30 42
S − 13	0 0	0 0	37 58	70 16	32 18

Table IV, be inspected, it will be seen that whilst the former are all zero (the light falling normally from the focus all over the

internal spherical surface), the latter are considerably greater than the corresponding angles of emergence in the case of P – 1 to P – 12. Thus the coefficients of loss by superficial reflection given by Mr. Allard for plano-convex lenses are not at all applicable to sphero-convex lenses.

In the meantime a comparison of losses by superficial reflection in the case of these two forms of lens may be made approximately as follows. Let the comparison be made between P – 1 to P – 9 and S – 1 to S – 10, or between plane and spherical lenses extending approximately to the limits of the spherical portion of a Fair Isle lens—supposing, however, all the elements to form complete rings. For elements P – 1 to P – 9, let the coefficients of Mr. Allard for combined losses be adopted. Table V gives the mean angles of incidence at entrance, the corresponding combined losses, the relative quantities of light incident on respective zones, and the products of the losses by the quantities of incident light. The sum of these products divided by the sum of the relative quantities is $\frac{0{\cdot}005986}{0{\cdot}11205} = 0{\cdot}05342$; which shows that the average loss by superficial reflection at entrance and at exit over the whole lens is 5·342 per cent. of all the incident light.

Table V.

Title of Element.	Mean Incidence at Entrance.	Combined Superficial Loss.	Relative Amounts of Light Received.	Product of Figures of the two Preceding Columns.
	° ′			
P – 1	4 4	0·0504	0·01006	0·000507
P – 2	10 0	0·0510	0·01137	0·000580
P – 3	13 26	0·0514	0·01257	0·000646
P – 4	16 18	0·0524	0·01299	0·000681
P – 5	18 48	0·0530	0·01312	0·000695
P – 6	21 0	0·0540	0·01292	0·000698
P – 7	22 59	0·0550	0·01295	0·000712
P – 8	24 49	0·0560	0·01294	0·000725
P – 9	26 32	0·0565	0·01313	0·000742
Totals . . .	..	..	0·11205	0·005986

Next, in the case of S – 1 to S – 10, it is evident that all the light reflected back from the spherical surface returns to the flame at the focus, a portion of it making its way through the flame and its surrounding glass chimney and passing on to the lens

of an opposite panel, whose emergent light it will reinforce after a further reduction in its passage through it. The amount of light so returned may be taken to be 2·5 per cent. of the incident light. Now, Mr. Allard has found by experiment that a 5-wick lamp absorbs nearly two-thirds of the light returned to it from a spherical mirror,[1] and the lamp suitable for such apparatus as that of Fair Isle being a 6-wick lamp at least, it may be inferred that the 2·5 per cent. of light returned will be reduced to 0·83 per cent. after traversing the flame. This amount will further be reduced to 0·73 per cent. in traversing the opposite lens. Hence, of the 2·5 per cent. of light returned, 0·73 per cent. is not lost, the actual loss at the inner spherical surface being (2·5 − 0·73) = 1·77 per cent.

In order to determine approximately the losses at the outer surfaces of elements S − 1 to S − 10, the following method may be adopted. For losses due to superficial reflection, Mr. Allard has given the following figures:—

0·05	0·052	0·058	0·075	0·120	0·230

for angles of incidence:—

0°	15°	30°	45°	60°	75°

These losses, however, as already mentioned, are due partly to reflection at entrance into and partly to that at exit from the glass. The angles of emergence which correspond to the foregoing angles of incidence in any plano-convex lens of glass whose refractive index is 1·53, are respectively—

0°	27°	48° 15′	63° 14	73° 12′	79° 5′

In order to obtain approximately losses due to the passage of light through a single surface, whether from air into glass, or *vice versâ*, in terms of the angle made by a ray with the normal in the air, let it be assumed that the losses indicated are double those which correspond to the means of corresponding angles of incidence and of emergence. These mean angles are:

0°	21°	39° 8′	54° 7′	66° 36′	77° 2′

and the losses are:

0·025	0·026	0·029	0·0375	0·060	0·115

Now, let abscissae proportional to the last-named angles be laid down from a given origin, and let ordinates be raised from their

[1] Mémoire sur l'Intensité et la Portée des Phares, p. 12.

extremities proportional to the last-named losses, and let a continuous curve be drawn through the extremities of the ordinates. In this way the loss at a single surface corresponding to any angle of incidence or of emergence can be obtained. The approximate losses corresponding to the mean angles of emergence of elements S – 1 to S – 10 have thus been determined, and are inscribed in the third column of Table VI below. The products of these losses, multiplied by the quantities of light received by

Table VI.

Title of Element.	Mean Angle of Emergence.	Loss by Superficial Reflection.	Relative Amounts of Light Received.	Product of the two Preceding Columns.
	° ′			
S – 1	9 58	0·0255	9·0	0·2295
S – 2	24 13	0·0265	16·6	0·4399
S – 3	31 56	0·0276	20·0	0·5520
S – 4	38 12	0·0288	22·5	0·6480
S – 5	43 19	0·0310	21·6	0·6696
S – 6	47 42	0·0334	23·5	0·7849
S – 7	51 40	0·0360	24·7	0·8892
S – 8	55 14	0·0392	25·5	0·9996
S – 9	58 29	0·0434	26·7	1·1588
S – 10	61 28	0·0482	27·9	1·3448
Totals . . .	..	..	218·0	7·7163

corresponding elements, are given in the fifth column. The sum of these products divided by the sum of figures of the fourth column, namely, $\frac{7\cdot7163}{218} = 0\cdot0354$, is the mean loss at emergence for elements S – 1 to S – 10. The whole loss by superficial reflection at emergence from these elements is, therefore, 3·54 per cent. of the whole of the light falling on the outer surfaces. Adding to this the amount lost at entrance, namely 1·77 per cent. the total loss by superficial reflection for the spherical lens considered is found to be approximately 5·31 per cent. The loss for the plane lens was found to be 5·342, so that a hardly appreciable advantage of 0·032 per cent. would rest with the spherical lens.

Finally, in reference to chromatic dispersion, the Author has satisfied himself, by one or two examples worked out, that this affects the spherical lens more unfavourably than the plane lens.

Doubts may arise as to the practical accuracy of the conclusions arrived at above, on the ground that the actual state of affairs in practice has not been considered. Objection may be taken to the assumption of spherical homogeneous flames at the foci of the lenses compared. It is evident, however, that, although ordinary flames present different faces, both as regards size and form, to points of a lens differently removed from the horizontal focal plane, upwards or downwards, whilst the hypothetical spherical flame presents a similar round face to every point, still these different faces are all acted on by the lens in the same fashion, that is, are in any plane of the generating section more and more elongated on passing outwards from the centre of the lens, and are simultaneously straitened more and more at right-angles to such plane. What are obtained, therefore, on the assumption of spherical flames, are not actual coefficients of lenses in combination with particular lamps, but their relative efficiencies in combination with any, the same, lamp. Thus, for any given lamp, the relative efficiencies of any number of lenses can be obtained, and that suffices to show which lens ought to be employed. If, also, the coefficient of one of the lenses with this lamp, say that for axial intensity, be obtained photometrically, then the coefficients for axial intensity of all the others with the same lamp can be at once deduced without further experiments. The assumption of homogeneity in the flame, that is, the assumption that it radiates equal amounts of light in all directions, must cause slight errors in the relative efficiencies obtained; but so long as lenses are compared in combination with similar lamps, and so long as the vertical angles of the lenses do not extend more than 32° beyond the horizontal focal plane, as in the case of the lenses compared in this Paper, these errors must be very slight, and not nearly sufficient to cause a wrong order in the relative efficiencies obtained. Further, it is worthy of remark that, for a flame of which the exact dimensions are given, as also the intensities of light emitted by it at different angles above and below the focal plane, it is possible by certain modifications of the method indicated above to calculate exactly the relative values of different lenses. The calculation would be more laborious than on the assumption of a spherical flame, but in no way more difficult.

Referring again to Fig. 2, considerable interest attaches to the comparison of the efficiency of the catadioptric portion of the lens with that of the dioptric portion, whether plane or spherical, suited to act along with it. Table VII has been drawn up for

this, just as Tables I and II were for the plane and spherical lenses.

In the case of a catadioptric prism, the natural divergence in all directions after emergence of the pencil of rays from a spherical flame at the focus, passing through any point of the inner refracting side, varies nearly in the inverse ratio of the whole distance travelled by the focal ray of the pencil up to the point at which it is reflected from the reflecting side of the prism.

TABLE VII.

1 Title of Element.	2 Limiting Angle from Axis of Lens.	3 Mean Focal Distance.	4 Mean divergence in all Directions for 140 millimetres Flame.	5 Cosine of Limiting Angle.	6 Relative Amount of Light received, supposing each Zone Entire.	7 Fraction of complete Zone acting.	8 Product of last two Columns, or Relative Light actually Received.	9 Product of Columns 4 and 8.
	° ′	Millimetres.	′					
SC – 1 . { lower	33 18	1,988	242	0·83581	0·01218	$\frac{300}{360}$	0·010150	2·4563
SC – 1 . { upper	34 33	..	..	0·82363	..	..	..	..
SC – 2 .	35 51	2,000	240	0·81055	0·01308	$\frac{272}{360}$	0·009880	2·3712
SC – 3 .	37 10	2,012	239	0·79688	0·01367	$\frac{252}{360}$	0·009990	2·3876
SC – 4 .	38 30	2,024	238	0·78261	0·01427	$\frac{236}{360}$	0·009355	2·2265
SC – 5 .	39 50	2,040	236	0·76791	0·01470	$\frac{222}{360}$	0·009065	2·1393
SC – 6 .	41 11	2,054	234	0·75261	0·01530	$\frac{210}{360}$	0·008925	2·0884
SC – 7 .	42 33	2,076	232	0·73669	0·01592	$\frac{200}{360}$	0·008844	2·0518
SC – 8 .	43 55	2,094	230	0·72035	0·01634	$\frac{193}{360}$	0·008715	2·0045
SC – 9 .	45 18	2,112	228	0·70339	0·01696	$\frac{184}{360}$	0·008668	1·9763
SC – 10 .	46 43	2,134	226	0·68561	0·01778	$\frac{172}{360}$	0·005530	1·2498
SC – 11 .	48 10	2,156	223	0·66697	0·01864	$\frac{70}{360}$	0·003620	0·8073
Totals .	..	..	..	..	..	..	0·092742	21·7590

And the mean natural divergence at emergence from a catadioptric prism is nearly equal to the mean angle subtended by the flame at the inner refracting side of the prism.

Column 6 gives the proportional parts of the entire sphere round the focus intercepted by the prisms SC, supposed complete, and column 7 gives the fractions of the entire rings actually utilized in the complete panel subtending 90° horizontally and 64° vertically. The mean divergence in all directions of the entire

catadioptric portion of the lens is found to be $\frac{21 \cdot 759}{0 \cdot 092742} = 234 \cdot 62'$.

Hence, neglecting losses by superficial reflection and by absorption, the efficiency of the catadioptric portion of the lens is to that of the corresponding spherical lens in the ratio $\frac{373 \cdot 38 \times 240}{234^2 \cdot 62} = 1 \cdot 628$, and to that of the corresponding plane lens in the ratio $\frac{(\frac{285}{240})^2 \times 246 \cdot 7 \times 221 \cdot 9}{234^2 \cdot 62} = 1 \cdot 402$. Thus, neglecting these losses, the catadioptric portion of the lens is 40·2 per cent. more efficient than the plane dioptric portion. And if the losses arising from all causes in the plane dioptric portion be put, as estimated by Mr. Allard, at 13 per cent., and in the catadioptric portion at 30 per cent., these figures of 100 and 140·2 become 87 and 98·14, or as 100 and 112·8.

The relative quantities of light received by the catadioptric prisms and by the plane lens DCE of Figs. 2, Plate 10, respectively, are shown by the totals of column 8, Table VII, and of column 6, Table I, and are as 9274·2 to 15164. And if these relative quantities be reduced 30 per cent. and 13 per cent. respectively, the relative quantities of light emitted would be 6,492 and 13,193. The former is, however, 40·2 per cent. more condensed than the latter; so that if the product of the quantity by the condensation be considered to form luminous momentum or power, then the relative (for the figures of quantity, as well as of condensation, are only relative figures) powers would be as 6,492 × 140·2 to 13,193 × 100, or as 910,178 to 1,319,300. Now, the price of the catadioptric portion would be to that of the plane portion as 6 to 5, so that for a given price, greater luminous power can be obtained from the plane dioptric portion. It must not be overlooked, however, that for a given amount of light received from the flame, the catadioptric portion gives the greater luminous power; for receiving about $\frac{9}{15}$ the amount of light received by the plane lens, the catadioptric prisms give about $\frac{9}{13}$ of the luminous power.

The Author was led to make these investigations on this account. Having doubts about the efficiency of the outer elements of the spherical lens of Figs. 2, he made, after completing the final adjustment of the catadioptric prisms in their frames, some rough and rapid photometrical measurements of the intensity of light emitted from successive dioptric and catadioptric zones. These experiments showed that the divergence increased with astonishing rapidity on passing outwards from the central lens along the other dioptric zones, as seen by the increasing breadth of emitted beams

received on screens, whilst the photometer showed a corresponding diminution of intensity. On arriving at the first catadioptric zone the breadth of the emitted beam was seen to be less than half that of the beam from the adjacent dioptric zone, whilst the intensity of the light was nearly double. These results caused the Author to investigate the matter by mathematical analysis, which confirmed and gave precision to the first rough experimental observations. The possibility then occurred to him of determining the relative efficiencies of different forms of lens by calculating their greatest and least divergences for a given flame, these divergences being inherent to and characteristic of each different form of optical agent used in lighthouse apparatus.

In conclusion, it may be well to sum up what has been accomplished in the Paper. In the Author's opinion it has completely shown for the first time how ex-focal rays are acted upon by the old plano-convex, and by the recently-suggested sphero-convex, dioptric lenses; and, although without detail, by the old catadioptric prisms; it has proved the old plano-convex lens to be unquestionably better than the sphero-convex lens in every circumstance; it has shown how the catadioptric prisms, when used to extend the horizontal compass of a lens, although more expensive than the central plane portion for a given luminous power sent out, are, nevertheless, better than the plane portion in this respect—that for a given amount of light received from the flame, they emit greater luminous power; and it has explained, with two important practical applications, a new method of determining the relative powers of lenses of different form.

The measurement of the value of different combinations of lighthouse-lamps and lenses is a somewhat difficult matter; and the fact that the figures given by Mr. Allard, who has been recognized as an authority on the subject since the publication of his Memoir in 1876, show intensities in general about twice as high as those deduced from the South Foreland experiments of 1884–5, although the lamps in the latter case were considered to be better, is enough to show that the problem in question is most likely to be satisfactorily solved by examination from all sides. It may, however, be confidently expected that, if both the methods dependent on mathematical analysis and on photometry be used to check each other, it will soon be possible to obtain figures that will be universally accepted.

The Paper is accompanied by 2 tracings, from which Plate 10 and the *Figs.* in the text have been prepared.

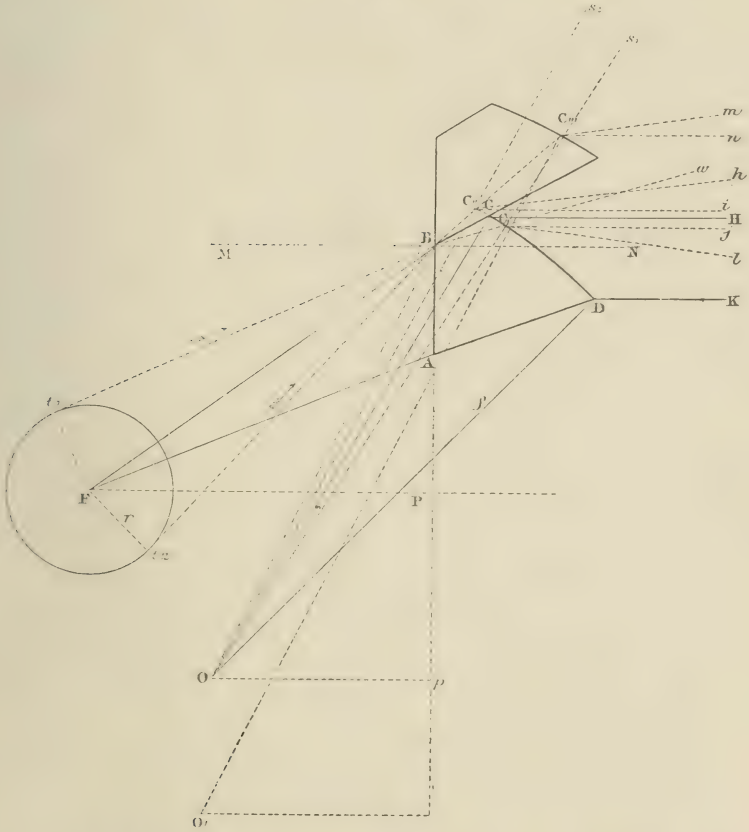
[Appendix.

APPENDIX.

Calculation of the divergence at exit from a plano-convex refracting lenticular element due to a spherical flame of given diameter in any plane of the generating section of the element. Index of refraction, $\mu = 1{\cdot}53$.

A B C D, *Fig. 4*, is a profile or normal section of a glass ring calculated

Fig. 4.



to refract the rays F A, F B into the direction D K, C H parallel to F P. On the point B and in the plane of the profile fall rays t_1 B, and t_2 B tangent to a spherical flame of radius r with its centre at the focus F; it is required to find the angle of divergence between these rays after their emergence from the glass. Let the given profile be P – 12 of Fig. 1, Plate 10. From the

data for the calculation of this profile and the results of its calculation, the following data necessary for the solution of the present problem are known: F P = 1,330 mm.; B F P = M B F = 31° 58′; C B N = 20° 15′; O p = 1,073·2 mm.; B P = 830 mm.; P p = 480·15 mm.; ρ = O C = O C_1 = O C_{II} = 1,698·1 mm. Besides r the radius of the flame = 46·55 mm.

The ray t_1 B is refracted along B C_1, and again along C_1 l. The ray t_2 B is refracted along B C_{II}, and may either be supposed to meet at C_{II} the arc D C produced and then pass out along C_{II} h, or else to go on and meet at C_{III}, the bounding arc of a succeeding profile, and pass out along C_{III} m. C_1 j, C_{II} i, and C_{III} n are drawn ‖ C H. M N is drawn ⊥ A B or ‖ F P. O and O_1 being the centres of the arc C D, and of the arc of the succeeding prism respectively, join O C_1, O C_{II}, and O_1 C_{III}, and produce O C_1 and O C_{II} to s_1 and s_2 respectively, also B C_1 to w.

The following are the steps necessary to determine the angles j C_1 l and i C_{II} h, the sum of which gives the angle of divergence between the rays t_1 B and t_2 B after emergence from the prism :—

$$\text{B F} = \text{F P} \sec \text{B F P} = 1{,}567{\cdot}7$$

$$t_1 \text{B F} = t_2 \text{B F} = \sin^{-1}\left(\frac{r}{\text{B F}}\right) = 1^\circ\ 42'$$

$$\text{M B} t_1 = \text{M B F} - t_1 \text{B F} = 30^\circ\ 16'$$

$$\text{C}_1 \text{B N} = \sin^{-1}\left(\frac{\sin \text{M B} t_1}{\mu}\right) = 19^\circ\ 14'$$

$$\text{O B} p = \tan^{-1}\left(\frac{\text{O} p}{\text{B P} + \text{P} p}\right) = 39^\circ\ 19'$$

$$\text{O B} = \text{O} p \operatorname{cosec} \text{O B} p = 1{,}693{\cdot}8$$

$$\text{O C}_1 \text{B} = \sin^{-1}\left\{\sin (90^\circ + \text{O B} p + \text{C}_1 \text{B N}) \frac{\text{O B}}{\rho}\right\} = 31^\circ\ 21'$$

$$s_1 \text{C}_1 l = \sin^{-1}(\mu \sin \text{O C}_1 \text{B}) = 52^\circ\ 46'$$

$$w \text{C}_1 l = \text{deviation} = s_1 \text{C}_1 l - \text{O C}_1 \text{B} = 21^\circ\ 25'$$

$$j \text{C}_1 l = w \text{C}_1 l - \text{C}_1 \text{B N} = 2^\circ\ 11'.$$

Next following the tangential ray t_2 B :—

$$\text{M B} t_2 = \text{M B F} + \text{F B} t_2 = 33^\circ\ 40'$$

$$\text{C}_{II} \text{B N} = \sin^{-1}\left(\frac{\sin \text{M B} t_2}{\mu}\right) = 21^\circ\ 15'$$

$$\text{O C}_{II} \text{B} = \sin^{-1}\left\{\sin (90^\circ + \text{O B} p + \text{C}_{II} \text{B N}) \frac{\text{O B}}{\rho}\right\} = 29^\circ\ 21'.$$

$$s_2 \text{C}_{II}\ h = \sin^{-1}(\mu \sin \text{O C}_{II} \text{B}) = 48^\circ\ 34'$$

$$\text{C}_{III} \text{C}_{II}\ h = s_2 \text{C}_{II}\ h - \text{O C}_{II} \text{B} = 19^\circ\ 13'$$

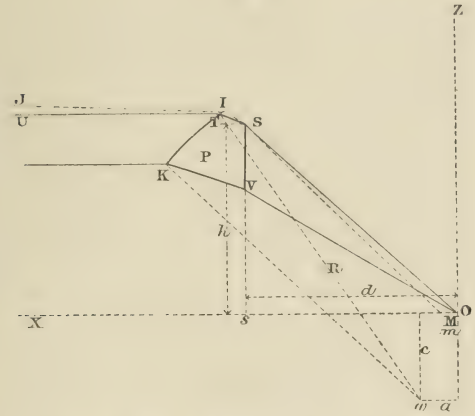
$$i \text{C}_{II}\ h = \text{C}_{III} \text{C}_{II}\ h - \text{C}_{II} \text{B N} = -\ 2^\circ\ 2',$$ the negative sign showing that this divergence is in the opposite direction from j C_1 l.

The angle of divergence at emergence of rays t_1 B and t_2 B therefore = 2° 11′ + 2° 2′ = 4° 13′. The corresponding angle of divergence for tangential rays incident at A being 4° 11′, the mean, or 4° 12′, or 252′, is the mean divergence at emergence for the element P − 12 as given in Table I. If the angle m C_{III} n be calculated it will be found to be within one minute of the angle i C_{II} h, so that it is immaterial whether the refracted ray B C_{II} be supposed to meet D C produced or to go on to meet the surface of a succeeding profile.

Calculation of the horizontal divergence at exit from a plano-convex refracting lenticular element of an outer ray issuing from the horizontal focal circumference of a flame at the focus and incident on the lens at any point on the line of intersection of a vertical axial focal plane with the inside of the lens.

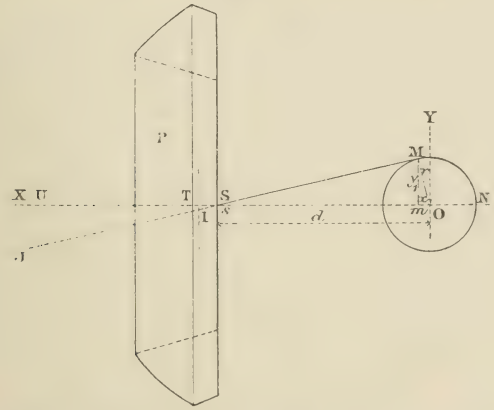
Let *Fig. 5* represent a vertical axial section through the refracting element P

Fig. 5.



and its focus O; and let *Fig. 6* represent a horizontal focal section, M N, of the flame, and the projection of the element P on the focal plane. Let M *s* be a ray tangent to the flame in the horizontal focal plane. It is required

Fig. 6.



to find the horizontal divergence of the ray M S, shown in horizontal projection in *Fig. 6*, and in vertical projection in *Fig. 5*, when it emerges from the element P along I J.

Since *s* M is less than *s* O, *Fig. 6*, the ray M S, *Fig. 5*, once refracted along S I will pass above S T, the path of O S after refraction at S, and meet the outer curved face produced at some point I, and be there refracted along I J.

Let O, the mathematical focus of P, be the origin of rectangular co-ordinates, O X, O Y horizontal axes, and O Z the vertical axis of co-ordinates, O X being coincident with the generating axis of P.

The data are, r the radius of the flame, d the principal focal length of P, h the height of S s, μ the index of refraction of the glass, all the results of the calculation of the profile P destined to send out the rays from O falling on S V $\parallel$ O X, including R the radius of curvature of the outer side, a and c the co-ordinates of the centre of curvature w, &c.

Let the points M, S, I have for their co-ordinates $(x_1\ y_1\ z_1)$, $(x_2\ y_2\ z_2)$, and $(x_3\ y_3\ z_3)$ respectively.

For the point M it is seen from *Fig. 6* that

$$x_1 = \mathrm{O}\,m = \frac{r^2}{d}$$

$$y_1 = \mathrm{M}\,m = \frac{r}{d}\sqrt{d^2 - r^2}$$

$$z_1 = \text{zero.}$$

For the point S again, *Figs. 5* and *6*,

$$x_2 = d$$
$$y_2 = \text{zero}$$
$$z_2 = h.$$

The surface of entrance is a vertical plane of which the equation is

$$x = d.$$

The surface of emission is a segment of the surface of a torus. The circular arc T K in the plane Z O X has for equation

$$(x - a)^2 + (z - c)^2 = \mathrm{R}^2,$$

and the equation to the torus generated by the revolution of the arc T K, about O X, is obtained by substituting $\sqrt{z^2 + y^2}$ for z in the above equation, whence

$$(x - a)^2 + (\sqrt{z^2 + y^2} - c)^2 = \mathrm{R}^2 \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Let the angle of incidence of M S at S be denoted by i, the corresponding angle of refraction by ρ, the angle of internal incidence at I by ϵ, and the corresponding angle of emergence by η.

Let the direction cosines of M S be		α_1, β_1, γ_1,
Those of	S I	α_2, β_2, γ_2,
Those of the normal at	I	α_3, β_3, γ_3,
Those of	I J	α_4, β_4, γ_4.

The direction cosine of M S with O X is given by the expression—

$$\alpha_1 = \frac{x_2 - x_1}{\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}},$$

or, after substituting for x_1, x_2, y_1, y_2, z_1 and z_2 their known values—

$$\alpha_1 = \frac{d^2 - r^2}{d\sqrt{d^2 + h^2 - r^2}} = \cos i.$$

Again, $\sin i = \mu \sin \rho$; whence $\cos \rho = \sqrt{1 - \frac{\sin^2 i}{\mu^2}}$.

Let the equation to the plane of incidence of M S be—

$$A x + B y + C z + D = 0,$$

then $A = 0$, because this plane is $\| O X$,

and $C h + D = 0$, because it passes through S,

and $B \frac{r}{d} \sqrt{d^2 - r^2} + D = 0$, because it passes through M.

Hence finally is obtained the equation of the plane of incidence—

$$\frac{d}{r \sqrt{d^2 - r^2}} y + \frac{1}{h} z - 1 = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Now S I has for direction cosines $\alpha_2, \beta_2, \gamma_2$, of which α_2 has already been found, since it equals $\cos \rho$, which equals—

$$\sqrt{1 - \frac{\sin^2 i}{\mu}};$$

also $\alpha_2^2 + \beta_2^2 + \gamma_2^2 = 1$,

and since S I has a point in common with the plane of incidence and is contained in it, S I is parallel to this plane whose equation is (2), therefore

$$r \sqrt{\frac{d}{d^2 - r^2}} \beta_2 + \frac{\gamma_2}{h} = 0,$$

therefore

$$- r \sqrt{\frac{\beta_2}{d^2 - r^2}} = \frac{\gamma_2}{h} = \sqrt{\frac{1 - \alpha^2}{\frac{r^2}{d^2}(d^2 - r^2) + h^2}} = \sqrt{\frac{\frac{\sin^2 i}{\mu^2}}{\frac{r^2}{d^2}(d^2 - r^2) + h^2}};$$

whence $$\beta_2 = - \frac{\frac{r \sin i}{\mu} \sqrt{d^2 - r^2}}{d \sqrt{\frac{r^2}{d^2}(d^2 - r^2) + h^2}},$$

and $$\gamma_2 = \frac{\frac{h \sin i}{\mu}}{\sqrt{\frac{r^2}{d^2}(d^2 - r^2) + h^2}},$$

and, as previously found, $\alpha_2 = \sqrt{1 - \frac{\sin^2 i}{\mu^2}}$.

Now, of S I are known the point S (d, o, h), and the direction cosines $\alpha_2, \beta_2, \gamma_2$, and its equation has the form—

$$\frac{x - d}{\alpha_2} = \frac{y}{\beta_2} = \frac{z - h}{\gamma_2} = \tau \, . \quad . \quad . \quad . \quad . \quad (3)$$

If τ denote the distance S I in equation (3), then x, y, z represent the coordinates x_3, y_3, z_3, of the point I, which, moreover, is a point on the torus.

Hence by (3)

$$\left.\begin{aligned} x_3 &= d + \alpha_2 \tau \\ y_3 &= \beta_2 \tau \\ z_3 &= h + \gamma_2 \tau \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

And substituting in (1)

$$(d + \alpha_2 \tau - a)^2 + [\sqrt{(h + \gamma_2 \tau)^2 + \beta_2^2 \tau^2} - c]^2 = R^2,$$

therefore,

$$\alpha_2^2 \tau^2 + 2 \alpha_2 \tau (d - a) + (d - a)^2 + h^2 + \gamma_2^2 \tau^2 + 2 h \gamma_2 \tau + \beta_2^2 \tau^2 + c^2 - 2 c \sqrt{(h + \gamma_2 \tau)^2 + \beta_2^2 \tau^2} = R^2$$

or

$$\tau^2 + 2 \{\alpha_2 (d - a) + h \gamma_2\} \tau + (d - a)^2 + h^2 + c^2 - R^2 = 2 c \sqrt{(h + \gamma_2 \tau)^2 + \beta_2^2 \tau^2},$$

and putting l for $\{\alpha_2 (d - a) + h \gamma_2\}$ and m for $\{(d - a^2) + h^2 + c^2 - R^2\}$

$$\tau^2 + 2 l \tau + m = 2 c \sqrt{(h + \gamma_2 \tau)^2 + \beta_2^2 \tau^2} = 2 c \sqrt{(1 - \alpha_2^2) \tau^2 + 2 h \gamma_2 \tau + h^2};$$

therefore

$$\tau^4 + 4 l^2 \tau^2 + m^2 + 4 l \tau^3 + 2 m \tau^2 + 4 l m \tau = 4 c^2 \{(1 - \alpha_2^2) \tau^2 + 2 h \gamma_2 \tau + h^2\}$$

and

$$\tau^4 + 4 l \tau^3 + 2\{2 l^2 + m - 2 c^2 (1 - \alpha_2)^2\} \tau^2 + 4 (l m - 2 h \gamma_2 c^2) \tau + m^2 - 4 c^2 h^2 = 0 \quad . \quad . \quad . \quad (5)$$

From this equation of the 4th degree in which τ is the only unknown, it can be found tentatively, a first approximation being the length S T of *Fig. 5*, which is known.

τ being determined, the co-ordinates of I, namely, x_3, y_3, z_3, are found from equations (4).

The next step is to determine the plane of incidence of S I on the torus. Let its equation be

$$A x + B y + C z + D = 0 \quad . \quad . \quad . \quad . \quad . \quad (6),$$

A, B, C, and D have to be found.

Since the plane passes through I,

$$A x_3 + B y_3 + C z_3 + D = 0,$$

and placing the value of D from this equation in (6).

$$A (x - x_3) + B (y - y_3) + C (z - z_3) = 0. \quad (7).$$

Again, expressing that S I is ‖ the plane of incidence,

$$A \alpha_2 + B \beta_2 + C \gamma_2 = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (8).$$

Further expressing that the normal to the torus at I is ‖ the plane of incidence.

$$A \alpha_3 + B \beta_3 + C \gamma_3 = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

From equations 7, 8 and 9, A, B and C can be eliminated, but it is necessary previously to determine the direction cosines α_3, β_2 and γ_3 of the normal at I.

They can be obtained from the formulas—

$$\alpha_3 = \frac{\frac{df}{dx}}{\sqrt{\left(\frac{df}{dx}\right)^2 + \left(\frac{df}{dy}\right)^2 + \left(\frac{df}{dz}\right)^2}}$$

$$\beta_3 = \frac{\frac{df}{dy}}{\sqrt{\left(\frac{df}{dx}\right)^2 + \left(\frac{df}{dy}\right)^2 + \left(\frac{df}{dz}\right)^2}},$$

$$\gamma_3 = \frac{\frac{df}{dz}}{\sqrt{\left(\frac{df}{dx}\right)^2 + \left(\frac{df}{dy}\right)^2 + \left(\frac{df}{dz}\right)^2}}$$

Now $f(x\ y\ z) = (x - a)^2 + (\sqrt{z^2 + y^2} - c)^2 - R^2$;

therefore $\frac{df}{dx} = 2\,(x - a)$

$$\frac{df}{dy} = 2\,(\sqrt{z^2 + y^2} - c)\,\frac{y}{\sqrt{z^2 + y^2}}$$

$$\frac{df}{dz} = 2\,(\sqrt{z^2 + y^2} - c)\,\frac{z}{\sqrt{z^2 + y^2}},$$

therefore

$$\left(\frac{df}{dx}\right)^2 + \left(\frac{df}{dy}\right)^2 + \left(\frac{df}{dz}\right)^2 = 4\,\{(x - a)^2 + (\sqrt{z^2 + y^2} - c)^2\} = 4\,R^2;$$

therefore

$$\alpha_3 = \pm\frac{(x - a)}{R};\ \beta_3 = \pm\frac{y}{R\sqrt{z^2 + y^2}}\,\{\sqrt{z^2 + y^2} - c\};\ \text{and}$$

$$\gamma_3 = \pm\frac{z}{R\sqrt{z^2 + y^2}}\,\{\sqrt{z^2 + y^2} - c\};$$

and since x, y, z are here x_3, y_3, z_3, which are known, $\alpha_3, \beta_3, \gamma_3$ are now also known.

Returning again to equations 7, 8, and 9, they furnish a determinant,

$$\begin{Vmatrix} x - x_3, & y - y_3, & z - z_3 \\ \alpha_2, & \beta_2, & \gamma_2 \\ \alpha_3, & \beta_3, & \gamma_3 \end{Vmatrix} = 0,$$

whence, by circular permutation, the equation to the plane of incidence of S I is obtained :—

$$(\beta_2\,\gamma_3 - \beta_3\,\gamma_2)\,(x - x_3) + (\gamma_2\,\alpha_3 - \gamma_3\,\alpha_2)$$
$$(y - y_3) + (\alpha_2\,\beta_3 - \alpha_3\,\beta_2)\,(z - z_3) = 0 \quad . \quad . \quad (10)$$

Now the angle of internal incidence at I of the ray S I has been called ϵ, and the angle of emergence η.

And $\sin\epsilon = \frac{\sin\eta}{\mu}$ by the law of refraction; but $\cos\epsilon$ is known from the formula,

$$\cos\epsilon = \alpha_2\,\alpha_3 + \beta_2\,\beta_3 + \gamma_2\,\gamma_3,$$

therefore $\sin\epsilon$ is also known,

and $$\cos\eta = \sqrt{1 - \mu^2\sin^2\epsilon}.$$

It is required now to find α_4, β_4, γ_4, the direction cosines of I J. For this purpose three equations are available, namely:—

$$\cos\eta = \alpha_3\,\alpha_4 + \beta_3\,\beta_4 + \gamma_3\,\gamma_4 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11),$$
$$\alpha_4^2 + \beta_4^2 + \gamma_4^2 = 1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12), \text{ and}$$
$$(\beta_2\,\gamma_3 - \beta_3\,\gamma_2)\,\alpha_4 + (\gamma_2\,\alpha_3 - \gamma_3\,\alpha_2)\,\beta_4 + (\alpha_2\,\beta_3 - \alpha_3\,\beta_2)\,\gamma_4 = 0 \quad (13),$$

the last equation expressing the fact that the emergent ray I J lies in the plane of incidence whose equation is (10).

From (11), $$\gamma_4 = \frac{\cos\eta - \alpha_3\,\alpha_4 - \beta_3\,\beta_4}{\gamma_3} \quad . \quad . \quad . \quad . \quad . \quad (14).$$

Substituting the value of γ_4 in (13), the value of β_4 can be deduced, thus

$$\beta_4 = \frac{\alpha_4\,\{\alpha_3\,(\alpha_2\,\beta_3 - \alpha_3\,\beta_2) - \gamma_3\,(\beta_2\,\gamma_3 - \beta_3\,\gamma_2)\} - \cos\eta\,(\alpha_2\,\beta_3 - \alpha_3\,\beta_2)}{-\beta_3\,(\alpha_2\,\beta_3 - \alpha_3\,\beta_2) + \gamma_3\,(\alpha_3\,\gamma_2 - \alpha_2\,\gamma_3)},$$

and α_4 being the only unknown in the right hand member of the last equation, β_4 can be equated to a known function of α_4, which may be called $f\,(\alpha_4)$. Then substituting this value of β_4 in (14), γ_4 is likewise equated to a known function of α_4,

namely $$\frac{\cos\eta - \alpha_3\,\alpha_4 - \beta_3\,f\,(\alpha_4)}{\gamma_3}, \text{ or say } \phi\,(\alpha_4).$$

And finally by (12)

$$\alpha_4^2 + \{f\,(\alpha_4)\}^2 + \{\phi\,(\alpha_4)\}^2 = 1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$

From this equation (15) α_4 can be determined, and then β_4 and γ_4, which were previously reduced to known functions of α_4.

The emergent ray is, therefore, now completely determined, since a point of it (x_3, y_3, z_3), is known, and its direction cosines α_4, β_4, γ_4.

What was ultimately sought for was the horizontal divergence of the ray I J; let this angle be called Δ, and its cosine α_5, then α_5 is found by the equation,

$$\alpha_5 = \frac{\alpha_4}{\sqrt{\alpha_4^2 + \beta_4^2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$

$$\text{and } \Delta = \cos^{-1}\alpha_5 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

Two examples of this problem have been worked out, namely, for the ray M S in the cases of P − 1 and P − 12 of Fig. 1, Plate 10. For P − 1, α_5 was found to be 0·9994035, which is the cosine of 1° 58¾′, and the focal distance O S is in this case 1·343 mm. The half of the unit-angle or $\sin^{-1}\left(\frac{r}{d}\right) = 120'$, and the ratio of this angle to the semi-horizontal divergence at S is therefore $\frac{120}{118\cdot75}$. The focal distances of the points of incidence corresponding to s and S (*Fig. 5*) are 1,330 and 1,343 respectively. If then the divergence vary in the inverse ratio of the focal distances, we should have the divergence at exit of the ray M S $= \frac{1,330}{1,343} \times 120' = 118\cdot83'$, and Δ has been found $= 118\cdot75$. Thus, in this instance, the inverse ratio of the focal distances of the points of incidence is the ratio of the respective divergences at right angles to a plane of the generating section.

For P − 12 the angle Δ was found $= 1°\,41\cdot86'$, or $= 101\cdot86'$; the focal distance of S was 1,567·7 mm., and $\frac{1,330}{1,567\cdot7} \times 120' = 101\cdot805'$, so that for this second

case also the divergences at right-angles to a plane of the generating section were found to be inversely as the focal distances of the points of incidence.

As stated in the body of the Paper, the internal angle of divergence of the flame in the horizontal focal flame at the centre of the lens has been taken as the unit-angle, because the corresponding angle of external divergence is there exceptional. To avoid reference to this position, the two examples worked out for the points S of P – 1 and P – 12 may be taken as means of comparison for positions where all is normal. If the law followed by the divergence at emergence from a lens at right angles to a plane of its generating section of extreme ex-focal rays from the flame at its focus be that of inverse proportionality to the focal distance of the point of incidence, then it should be found that $\frac{1,343}{1,567 \cdot 7} \times 118 \cdot 75 = 101 \cdot 805$, and actually the former expression is equal to 101·73. This law may therefore be considered to be established.

(*Paper No. 2577.*)

"Permanent Way for Viaducts."

By Herbert Tatham Procter, Assoc. M. Inst. C.E.

A glance through the Subject-Index of the Minutes of Proceedings of the Institution suggests that "Permanent Way" is a question to which railway engineers have paid great attention, and that it is almost inexhaustible. In adding one more contribution to the literature of the subject, the Author proposes to confine himself to a branch that has not hitherto been specially selected for notice in the records of the Institution, probably on account of the comparative smallness of viaducts. It now, however, seems worthy of consideration, since the construction of several important viaducts abroad, and of two notable examples in this country, viz., the Forth and Tay bridges. During the designing and construction of the last-mentioned viaduct, it was natural that the engineers, before laying down thereon nearly 4 miles of Permanent Way (2 miles of double line), should carefully consider different modes of construction, particularly those in use on other viaducts, before deciding upon the design. Whilst working for many months almost entirely on this subject, for Messrs. W. H. Barlow & Son, the Author collected the information contained in this Paper, and he hopes it may prove a useful reference for young engineers.

He proposes to discuss:—(1) The best method of laying the road; (2) guards; (3) expansion rail-joints.

Laying the Road.

In February, 1861, at the close of a lengthy discussion at the Institution, on the merits of various kinds of Permanent Way,[1] Mr. G. P. Bidder, President, observed that—

"The experience of the last twenty-five years had shown that one system had been adopted almost universally, the double-headed rails upon chairs, with cross-sleepers, a plan which had been materially improved by fishing the joints.

[1] Minutes of Proceedings Inst. C.E., vol. xx. p. 290.

The ingenuity of inventors had been exercised, the bridge-rail and many other descriptions had been introduced; but none had met with universal success. His own conviction was that the double-headed rail, when of proper materials, with properly proportioned chairs, and properly fished, was the safest and the nearest approach to perfection that could be practically obtained."

As this view is now confirmed by the further experience of the past thirty years, the Author adopts it as an axiom. Then, since it is granted that a cross-sleeper road is in every way the best, it should be the practice of engineers to lay down this form of permanent way over viaducts. Although, in the construction of a viaduct, the permanent way is the last thing that the engineer has to pay attention to, in designing the structure the reverse is the case; for on that point depends the form of the flooring to be used, and consequently, to some extent, the form of girder. Until quite recently, it was customary to construct the flooring of a viaduct by fixing at intervals strong cross-girders resting on, and at right-angles to, the main girders; and then to place between or upon these, lateral girders, either of iron or wood, parallel to the main girders, forming a continuous support on which to place the rails, filling up the open spaces left with buckle-plates, ordinary planking, &c.; this naturally gave rise to the majority of longitudinal way-beam roads over viaducts.

Oddly enough, in the very year that the above-mentioned opinion with regard to permanent way was expressed by Mr. Bidder, Mr. William Humber, in "Iron Bridge Construction," stated, with reference to the flooring of viaducts, that the most satisfactory system that could be adopted was that in which the platform consisted of a considerable number of cross-girders placed moderately near together. The load is thus transmitted to the main-girders at a great number of points and the undulation of the platform is counteracted, and, in addition, where the platform is kept as narrow as possible, the system is actually the lightest and most economical. This statement again has been fully borne out in practice, and now the ordinary type of flooring is a platform consisting of cross-girders so close together that their top and bottom flanges actually touch alternately; thus producing a series of troughs and ridges of sufficient strength to bear any weight that the viaduct may have to carry, and of such dimensions that the troughs are suitable to receive sleepers packed in ballast at the proper intervals. Most of these floorings are well known, and need not be described; but the Author would like to direct attention to the two forms invented many years ago by Mr. W. H. Barlow, and now in general use; these were fully described and

illustrated in Mr. Crawford Barlow's Paper on "The Tay Viaduct, Dundee."[1]

With such facilities for laying cross-sleeper and ballast roads over viaducts and bridges, there can be little doubt that this kind of road will take the place of the longitudinal way-beam road. The advantages of the former over the latter are numerous. It is simpler to lay, to adjust, and to renew. It avoids serious difficulty from camber in girders. It deadens noise and vibration. It distributes the moving load over the whole width of the flooring. It allows expansion and contraction of the rails to take place independently of the viaduct. It is less costly, because it lasts longer—the wear and tear of longitudinal beams exposed to the weather being greater than that of sleepers bedded in ballast; and, in addition to the wear from natural causes, there is, in the case of a longitudinal road which must be fixed to the flooring, the tearing of the attachment-bolts, due to the unequal expansion and contraction of the timber way-beam and the metal girders. The single drawback is that the ballast road is heavier; and, where great strength is required, the depth of the troughs is often greater than is necessary to contain the sleepers and a sufficient quantity of ballast, and the extra ballast adds useless weight; although this may be considerably reduced by several simple expedients, involving but slight increase in cost: *e.g.*, by confining the ballast to that portion of the trough immediately under the sleeper; by placing across the troughs, at the requisite depth, arched diaphragms, like buckle-plates, supported, if necessary, by angle-bars; by circular or semi-circular pipes fixed at the bottom of the troughs, and other such-like simple contrivances. The ballast itself should be very carefully prepared from light and suitable materials: a mixture of ashes and slag will be found serviceable—moisture greatly increases the weight of ashes, but has little effect upon slag, as the following figures taken from actual weighings will show:—

Ashes, dry and not punned	weigh	. 42 lbs.	per cubic foot.
„ damp „	„	. 60 „	„
„ very wet and punned hard	„	. 84 „	„
Slag, dry and coarse	„	. 71 „	„
„ „ and small	„	. 75 „	„
„ [2] wet and small	„	. 76 „	„

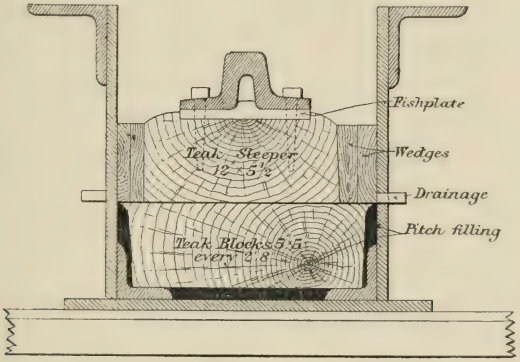
Thus, by placing the coarse slag in the bottom of the troughs,

[1] Minutes of Proceedings Inst. C.E., vol. xciv. p. 87.

[2] After being soaked in water for half-an-hour.

and then adding the fine slag and ashes, perfect drainage is ensured, weight avoided, the life of the sleepers prolonged, and they are laid in the usual way. In all cases where ballast is used in troughs, it is necessary that the ironwork be well asphalted or tarred, and also that there be ample provision for drainage. Should a longitudinal-sleeper road be requisite, the designing and laying becomes a complicated affair. The method of attachment of a longitudinal way-beam to a wooden flooring presents no difficulty; but, when the attachment is to metal, the case is different, as the beam has to be continually altered or renewed, in consequence of the wear and tear arising from vibration and unequal expansion. To attach the beam directly to a metal decking is almost out of the question, as it involves inserting bolts,

Fig. 1.



Forth Bridge.

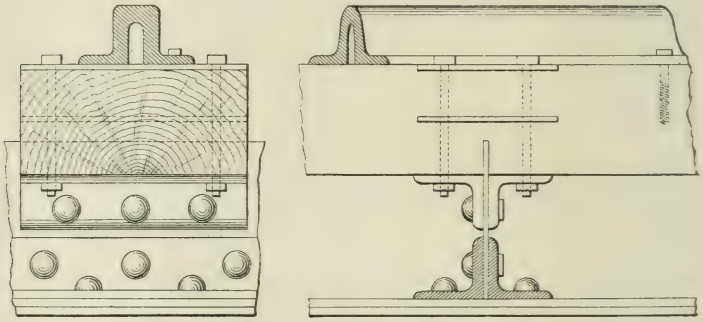
or screwing up bolt-heads from underneath; and this, in many cases of hog-backed, bow-string girders, &c., where the decking is on the bottom boom of the girders, is an expensive and lengthy proceeding.

The elaborate construction of the longitudinal road over the Forth Bridge may be taken as a proof of the necessity for avoiding these difficulties. A cross-section of this is shown in *Fig. 1.* It will be noted that the fitting of the way-beam requires six pieces of timber; also that the trough in which the timber is contained is built of three plates and four angle-bars (two of these latter being for the guard). The difficulties are certainly overcome; the timber has only a frictional attachment to the metal of the viaduct, it is well encased and so should wear well, no lateral motion can take place, and the road is probably as elastic as any

longitudinal road can be; but the method of construction can hardly be considered suitable for an ordinary viaduct.

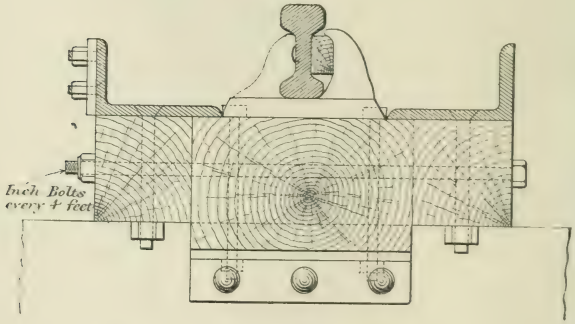
The Britannia Tubular Bridge over the Menai Strait, furnishes another instance of the difficulties of attaching a longitudinal road to an iron flooring composed of plates riveted to tee-bars, strengthened at 6-feet intervals by the insertion of transverse keelsons that stand up to a height of 9 inches from the level of

Figs. 2.



Britannia Tubular Bridge (Old Road).

Fig. 3.



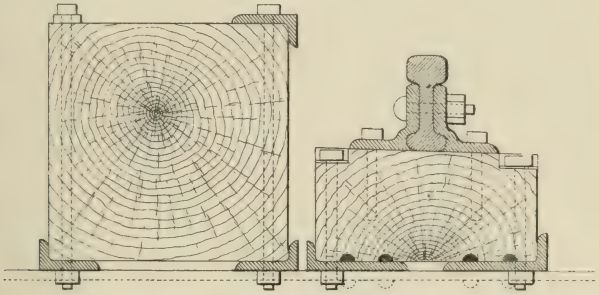
Britannia Tubular Bridge (New Road).

the floor. On each side of these keelsons, 2 inches from the top, are riveted horizontal angle-irons 14 inches long (*Figs. 2* and *3*) immediately under the way-beams, which are then slotted to receive the keelsons, and are securely bolted down to the angle-irons upon which they rest. At the joints of the timber and rails, plates are used to ensure a firm connection. The rail first used was an ordinary bridge-rail, *Fig. 2*, but this has since been changed

to the bull-headed rail and chair generally in use on the London and North Western Railway, *Fig. 3.* At the Conway Bridge, similar in most respects to the Britannia and opened at about the same time, the permanent way was laid in the same manner ; but the bull-headed rail was used from the first, the chairs being placed 2 feet on each side of the keelsons to give greater elasticity ; and a heavy rail was used, probably on account of the greater distance, viz., 4 feet, between the chairs.

An effective and simple method is to rivet on to the surface of the decking two angle-bars to contain the base of the beam, (*Fig. 4*). This may be done while the decking is being riveted up; and the shoe thus formed by the angle-bars becomes part of the floor, supported by and attached to each ridge, while in each trough it is unsupported; and, consequently, if the beam is attached by bolts to the shoe directly over a trough, the bolt-

Fig. 4.



New Tay Viaduct—Design Submitted.

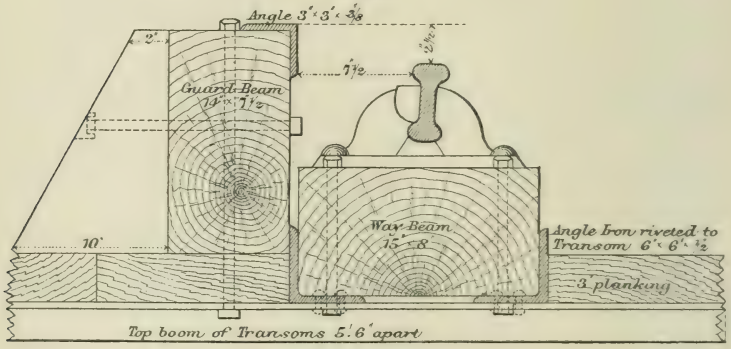
heads or nuts can be manipulated from the upper side of the flooring. The shoe thus formed will effectively prevent lateral motion of the beams, and vertical motion is prevented by the vertical bolts. The angle-bars used must depend on the scantling of the way-beam ; thus, for an ordinary way-beam of, say, 14 inches by 7 inches, two angle-bars of 5 inches by $2\frac{1}{2}$ inches by $\frac{1}{2}$ inch would be ample, as in *Fig. 4.* On the Montrose Bridge, *Fig. 5*, a way-beam, 15 inches by 8 inches, is used, with angle-bars 6 inches by 6 inches by $\frac{1}{2}$ inch.

On two of the Cheshire Lines viaducts over the Manchester Ship Canal, where the decking is similar to that used on the New Tay Viaduct, an attachment like this is used, the Railway Company having stipulated for a way-beam, 24 inches by 6 inches, covered with galvanized sheet-iron, to accommodate a double chair and

guard-rail. The angle-bars are 4 inches by 4 inches by $\frac{1}{2}$ inch, and a horizontal bolt passes through the vertical limb of the angle-bars and the way-beam at every 2 feet 6 inches, the beam being tightly packed with strips of greenheart. By having a 4-inch vertical limb to the angle-bars the attachment of the way-beam is a simple matter; but it must be borne in mind that such projections are awkward additions to the decking during construction. Another questionable feature in this case is the size of the way-beam, 24 inches by 6 inches, which has had to be made in two pieces; the chair used is only 16 inches wide, and a way-beam of 16 inches by 8 inches might have been used with advantage.

It is interesting to observe the changes in the mode of laying that have occurred in the practice of the London and North

Fig. 5.



MONTROSE BRIDGE.

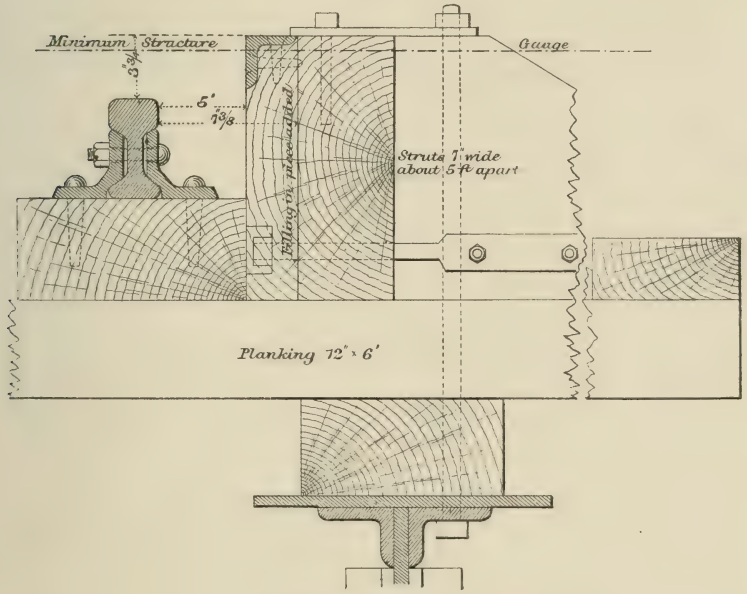
Western Railway Company. They first laid a bridge-rail on the Britannia Bridge, which they subsequently changed to an ordinary rail and chair, having found this to work satisfactorily on the Conway Bridge, and, doubtless, wishing to adhere to a uniform system of permanent way; now, on the new deviation viaduct of the main line over the Manchester Ship Canal, they are reverting to a longitudinal road and bridge-rail similar to that in *Figs. 2.* In cases of old viaducts or other situations, where a longitudinal road is necessary, the Author is of opinion that it is a mistake to use chairs and bull-headed rails, as these not only raise the bearing-surface of the rail, and thus increase the lateral stress on the attachments of the way-beam, but they do away with the main advantage to be derived from a longitudinal way-beam, viz., continuous bearing, which can be obtained by the use of a bridge-

rail, as in *Figs. 1* and *2*, or a flat-bottomed rail, as used by the Great Western Railway; or, if it is thought desirable to adhere to the rail in general use on the system, this can be done by the adoption of angle-bar fish-plates, as in *Figs. 4* and *6*, which is a pattern much used on the viaducts of the Midland Railway.

Guards.

The question of what forms an efficient guard on a viaduct appears (as may be seen from a glance at the various types shown

Fig. 6.



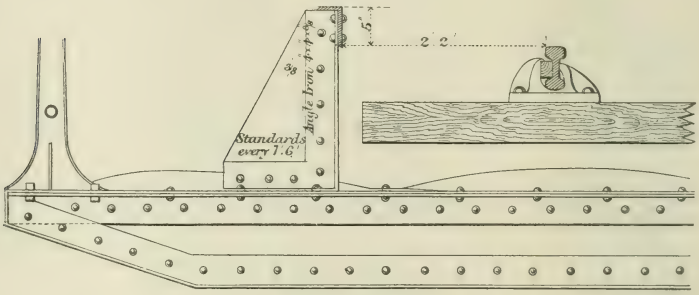
Halesowen Viaduct.

in the *Figs.* that accompany this Paper, nearly all of which have been passed and are types now in use) to admit of various interpretations by the Board of Trade Inspectors. The official requirement runs thus: "In important viaducts substantial guards should be fixed outside, above the level of and as close to the rails as possible, but not so as to interfere with the steps or any of the working-parts of the engines or trains." This regulation was no doubt framed in the days of the cross-girder and timber flooring, alluded to above. Then it was essential that the train should not

leave the immediate vicinity of the rail, or it would break through the thin timber flooring between the cross-girders. Now, with steel or iron floorings over the whole surface of a viaduct, if a train does leave the rails, it stands as good a chance of remaining on the top of the flooring in one place as another; and, consequently, if the guard be placed at the extreme edge of the viaduct, to prevent the train from going over the side, it may possibly be considered as useful (it is certainly out of the way) there, as in any other position. The Author does not state this as his view, but suggests it as an explanation of the reasons why the guards shown in *Figs. 7* and *10* have been sanctioned.

The obvious suggestion of the regulation under discussion is that a duplicate guard-rail should be placed on the outside of the running rail and slightly above it (*Fig. 8*), in much the same way that a check-rail is used, and this has been done in many small

Fig. 7.



Stirling Bridge.

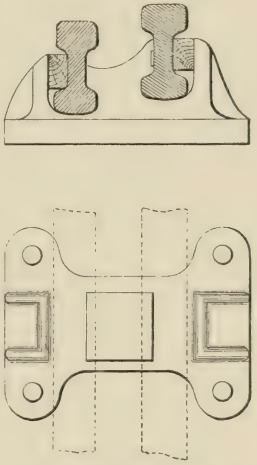
viaducts, and is being used on two of the deviation viaducts in connection with the Manchester Ship Canal. It was arranged thus in the old Tay Bridge, and a somewhat erroneous idea existed at the time of the catastrophe—is even quoted now—that the probable cause of the failure was the train leaving the metals and colliding with the girders. If this were so, the guard-rail used could not be deemed an efficient one. But the evidence given at the inquiry on this point pointed rather to the probability that the rear carriages of the train were canted over by the force of the wind, the leeward guard-rail in all probability keeping the wheels on the rails.

Fig. 8 is the form of double chair which was used on the old Tay Bridge, the guard-rail being 2 inches away from and 1 inch above the running-rail. Comparing with this the wheel, with

flange, as used on the North British Railway, *Fig. 10*, it will be difficult to see how such a wheel could get off the line.

The guard-rail is usually fixed, as shown in *Fig. 8*, by means of a double chair, but, should such chairs be unobtainable for any reason, two ordinary chairs may be used, as shown in *Fig. 13*, the outer one being raised by packing. This, of course, has several objections; the space between the rails is increased, and would allow of the wheel getting off, in which case it would jolt over the chairs until brought to a stand-still. An objection to all guard-rails of this class is that cases have been known where pieces of metal, &c., have fallen from a train and become fixed between the guard- and running-rails, and have actually thrown the train off the line. A form of guard which also nearly conforms to the Board of Trade regulations is shown in *Figs. 1* and *3*, and it may be added that these have proved effective time after time. In this case the rail runs in a trough, which is formed in various ways. If a vehicle is de-railed, it simply runs in the trough instead of on the rails. It is interesting to note that this form of guard is used on both the first and last great engineering marvels in metallic bridge-building in this country, viz., the Britannia Tubular Bridge and the Forth Bridge, to which *Figs. 3* and *1* respectively relate. On both of these bridges there is evidence of the guard having been effectual. In the case of the Britannia Bridge, when the permanent way was first laid, no guard of any description was provided (*Fig. 2*); and, in order to make a bearing for the two angle-bars that form the trough, it was necessary to bolt on to the existing way-beam two other beams resting on the keelsons (*Fig. 3*). Doubtless, if the road were being relaid throughout, a more convenient form of timbering might be adopted. Of the two types shown, a casual observer would probably prefer the one just described (*Fig. 3*), as its attachment seems simpler. It has also, on each side of the rail, a plain level metal surface for a de-railed train to run on. But the Forth Bridge type has many advantages—chiefly those of resistance to lateral motion (the trough forming part of the floor); protection to the timber, being

Figs. 8.

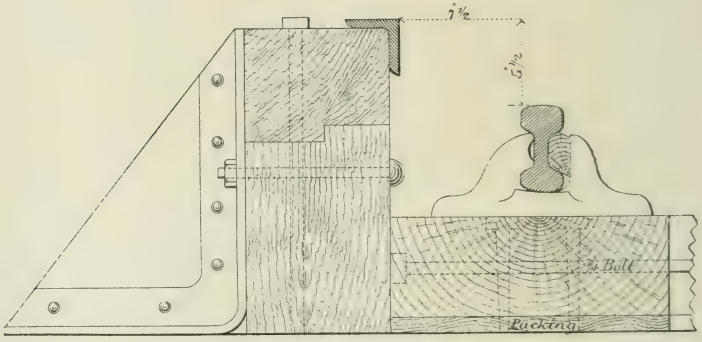


Old Tay Bridge.

encased all round; and the arched form of the way-beam causing a de-railed wheel to run clear of the spike-heads. Both forms are no doubt expensive and troublesome to lay, but are thoroughly reliable and satisfactory in use.

Passing to another type of guard which is still "near the rail and above the level of it," large timber baulks, as illustrated in *Figs. 4* and *12*, are much used on old timber structures, particularly in America. These need little remark. The attachment to the flooring is the important point to pay attention to. The method advised in the first part of this Paper for securing way-beams applies here also, if the decking is of iron (*Fig. 4*). What has to be chiefly guarded against is the liability to overturn if a heavy weight strikes against the inside; and various

Fig. 9.



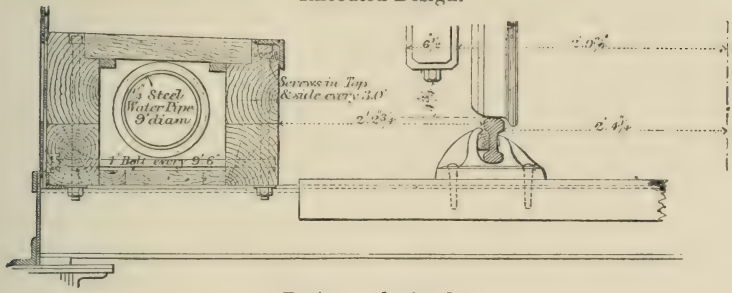
Ribble Bridge.

methods of struts, angle-irons and bolts, are shown to prevent this (*Figs. 4*, *6*, *9* and *12*). A small angle-bar should always be placed on the corner of the baulk nearest to the rail, and is neater when let into the timber. The height of the baulks depends on the rolling-stock that passes over the viaduct. *Figs. 1* to *14* illustrate types used by different railway companies, hence the difference in the height of the top of the guards above the rail-level, to comply with the regulation that the guard must be "so placed that it does not interfere with the steps or any of the working parts of the engines or trains." The Author, in working out designs for the guard for the New Tay Viaduct, was of course guided by the rolling-stock of the North British Railway. A guard of this kind may be easily attached to a cross-sleeper road by means of fang-bolts and short angle-bars; the attachment

NEW TAY VIADUCT.

Fig. 10.

Executed Design.



Designs submitted.

Fig. 11.

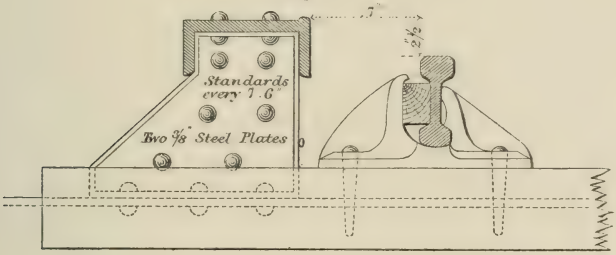


Fig. 12.

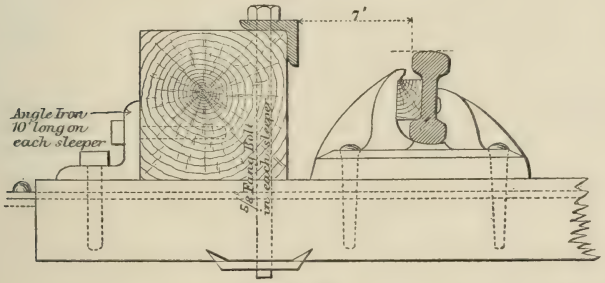
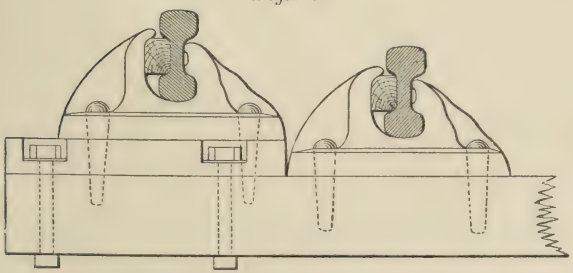


Fig. 13.



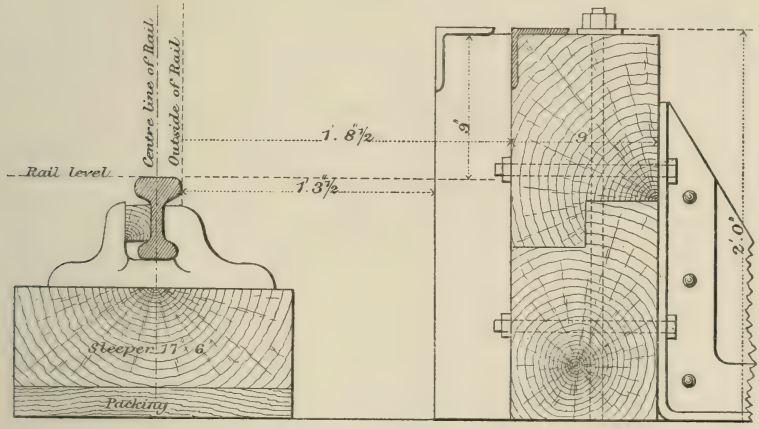
being to the sleepers and not to the deck-plating (*Fig. 12*). Guards may be constructed of heavy channel-bar, or even angle-bar (*Figs. 7* and *11*), supported at intervals by standards attached to the decking. This is becoming a favourite guard on new viaducts, and is applicable to both longitudinal and cross-sleeper roads. The standards, being placed on the ridges, do not interfere with cross-sleepers, which can pass under the channel-guard, as in *Fig. 11*. This form of guard is now extensively used on the North British Railway, and at one time it was intended to erect one on the New Tay Viaduct; but, in this case, although the guard-rail was all important, there was a secondary consideration in the form of a 9-inch water-main which had to be carried over the bridge. This main had also to be suitably protected against variations of temperature and damage from the traffic, thus involving a strong and somewhat bulky casing that projected almost to where the guard would be placed. Hence arose the idea of increasing the strength of the case and protecting it with an angle-iron on the outside corner; and it finally assumed the form shown in *Fig. 10*, which illustrates the guard actually employed on that bridge. There is, of course, a similar guard on the other side of the viaduct, which contains telegraph- and signal-wires. Both are strengthened by struts placed at about every 9 feet, in addition to 3-inch planking framed into the top; they are asphalted, and form convenient and safe footpaths for workmen along the sides of the viaduct. *Figs. 4*, *11*, *12* and *13* were designs submitted for the New Tay Viaduct, with a view to meet more nearly the Board of Trade regulations. But as there was no question as to the capability of the flooring, even if a train left the rails, and as there existed, on the neighbouring bridge over the Forth at Stirling (*Fig. 7*), a "sanctioned" example of a guard considerably removed from the running rail, those designs were abandoned in favour of that shown in *Fig. 10*, for the reason explained above. The Earn Viaduct also has a guard similar to that in *Fig. 7*, 2 feet 2 inches from the rail, but rising 15 inches above it.

Before leaving this part of the subject, two cases may be mentioned where difficulties have arisen as to the position of the guards. The West Lancashire Railway Company were made, under protest, to fix a guard on the River Douglas Bridge (*Fig. 14*), 15½ inches from the rail; this was afterwards altered, as shown, to 20½ inches.

A more noteworthy instance is that of the Halesowen Viaduct on the Midland Railway, illustrated in *Fig. 6* previously referred to. Here the guard was originally fixed, and sanctioned by the Board of Trade, 7⅜ inches from the running-rails, and the height above the

rails was more than 3 inches—that is, higher than the minimum structure gauge. This was afterwards altered, the height being reduced to 3 inches, and a filling-piece added to the side, so as to reduce the distance to 5 inches from the rail. This viaduct, like that of the Tay, has a sharp curve in one portion, and, consequently, the way-beam is canted to allow for super-elevation, and a check-rail is also used. In the case of the Tay Viaduct, some difficulty was experienced in laying the rails and guard on the sharp curve; the rails, of course, followed the curve, while the guard followed

Fig. 14.



River Douglas Bridge.

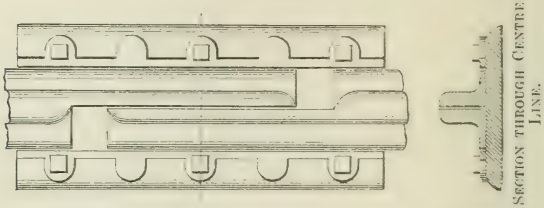
the line of hand-rail—that is, of the girder—and had a tendency to become tangential to the rails.

Expansion Rail-Joints.

Now that bridge spans are increasing so greatly, the expansion and contraction of the great lengths of metal used presents important questions. As the bridge itself expands, so approximately do the rails also; and where the former expansion is provided for, the latter must also be considered. This is particularly important in longitudinal roads, which are invariably attached to the bridge itself; hence the advisability of cross-sleeper and ballast roads wherever feasible. In the nature of things, it is not to be expected that a simple rail of iron, probably shaded at times from the sun, should expand exactly as does a complicated lattice-girder or the limbs of a cantilever. If the

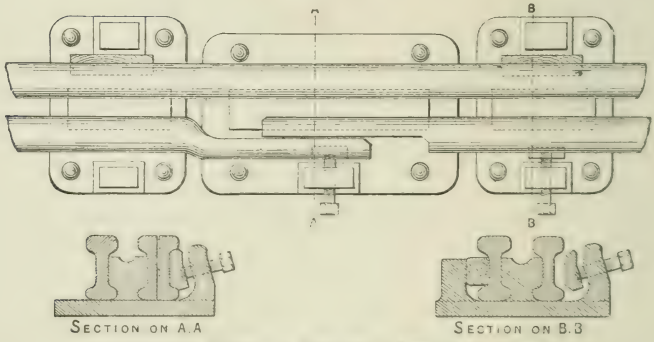
rail is fixed to a way-beam, which in turn is attached to the platform of the structure, the expansion of the rail and its supports being unequal, the attachments must tend to work loose. The Author suggests that working loose is due more to this cause than to the jar and vibration caused by passing trains. Hence the advantage of the absence of all attachment, except that afforded by ballast, between the sleepers and the floor of a viaduct. It was probably not until the building of the Britannia Tubular Bridge in 1845, where there are two spans of about 460 feet, that

Figs. 15.



Britannia Tubular Bridge (Old Rail-Joint).

Figs. 16.

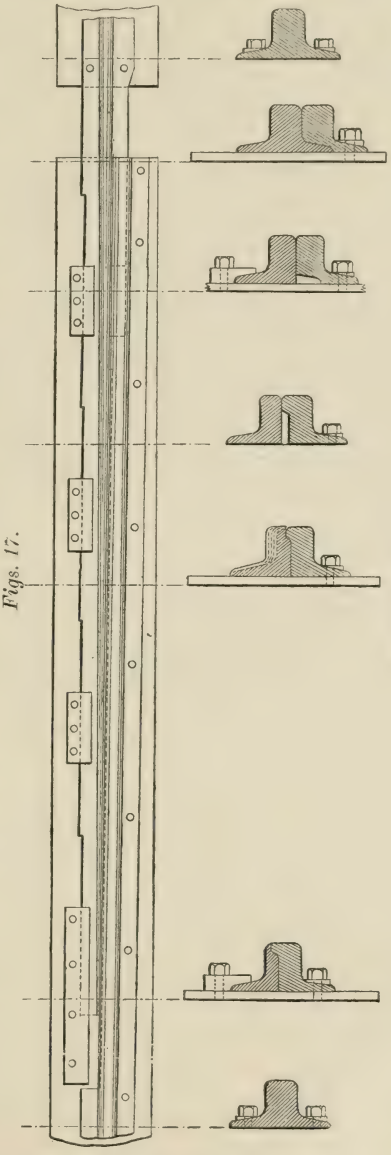


Britannia Tubular Bridge (New Rail-Joint).

any special arrangements were made for the expansion and contraction of the rails, estimated in this case at 3 to 4 inches. Here two split solid bridge-rails of somewhat primitive form provided for this expansion (*Figs. 15*). It will be noticed that the divided rails simply rest in a groove that ensures their mutual contact; but no attempt is made to hold them down; also, that no check-rail is placed at the joint; but provision is made for the slight alteration in gauge by placing the joints, not opposite to one another, but about 6 feet apart. This arrange-

ment necessitated the whole of that 6-feet length of rail being unattached to the floor, and therefore liable to lateral motion.

In the Conway Bridge, built at the same period, a similar joint was made; but, in this case, with an ordinary flanged-rail and chair; a check-rail was also used. These features have since undergone alteration. A bull-headed rail has been substituted for the bridge-rail at the Britannia Bridge. A system of chairs holds the split-rails at the expansion-joint, as shown in *Figs. 16.* The two defects in the original joint being overcome by the rails being securely held down and by the addition of check-rails.



Figs. 17.

FORTH BRIDGE.

Figs. 17 show the expansion rail-joint in use at the Forth Bridge. Here movement is allowed for to the extent of 2 feet at the sliding-ends of the central girders; at the ends of the fixed cantilevers, 1 foot is allowed for, and smaller movements are provided for elsewhere. The rail-joints at these places are all arranged on the same principle. As before mentioned, a bridge-rail is used, and runs in a trough. The rail on one side of the joint is continued across into the opposite trough, the projection being tapered to a point on the outside at 1 in 63; the rail it would otherwise butt against being bent outwards at the same angle, the con-

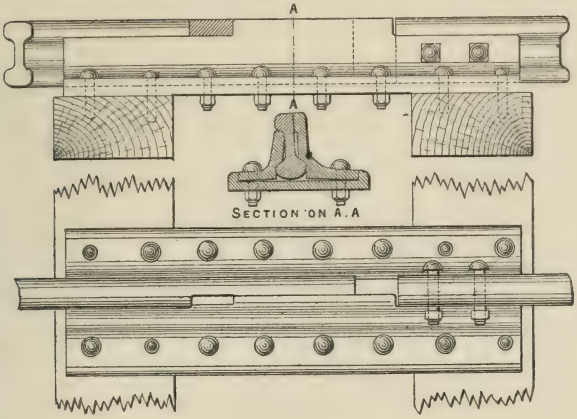
tiguous flanges being cut away. The flange on the inside of the tapered rail is cut in steps to the same angle—the length of the steps being fixed by the amount of movement required—and at each step there is a clip securely fixed to a plate, on which the tapered rail simply rests, but to which the other rail is securely bolted. The tapered rail can thus slide in either direction, but is kept down on the plate by the clips, and hard against the other rail by means of the sloping steps. Thus the correctness of the gauge is ensured.

The total expansion and contraction to be provided for in the New Tay Viaduct was estimated at 5 feet; the length of the viaduct being about 10,500 feet, and the extreme variation in temperature 75° Fahrenheit. Expansion was provided for at 32 places, and as there were consequently 128 expansion rail-joints, it was necessary that they should be of a simple kind. The maximum movement allowed for in one joint was 3 inches; and *Figs. 18*, *19* and *21* show some of the joints proposed. The one first selected was that illustrated in *Figs. 19*, and several of these were made and placed on the viaduct; it being thought that by joining two chairs, thus forming a continuous bearing for the weak part of the rail, all difficulties would be overcome. Such was not the case, however; as, owing to the elasticity of the road, the key at the joint did not prevent the rails from springing vertically, and considerable "hammering" was produced. The joint was consequently replaced by the one shown in *Fig. 20*, where it will be seen that the rails are tongued and grooved into one another, and strongly fished. This joint has proved satisfactory. It may here be mentioned that, during the first 12 months, daily observations were made of the movements due to variation of temperature, on a length of 516 feet. The greatest variation of temperature recorded during the year was 55° Fahrenheit, and the maximum movement of the rail 1·6 inch. In any case where continuous angle-iron fish-plates are used and only a small movement is anticipated, a joint like that in *Figs. 18* might be adopted with advantage. The rail is very slightly interfered with, one of the top flanges only being taken off; and the fish-plate on that side, being strengthened and continued up to the level of the rail, would prevent any hammering of the wheels whilst passing over the gap caused by contraction. The same result would be obtained by the specially-constructed chair shown in *Figs. 21*.

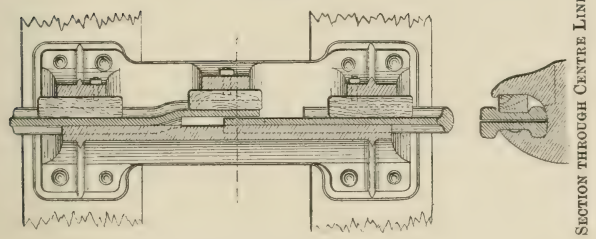
In support of the opinion expressed in this Paper—that a cross-sleeper and ballast road is preferable to a longitudinal way-beam

NEW TAY VIADUCT.—RAIL-JOINTS.

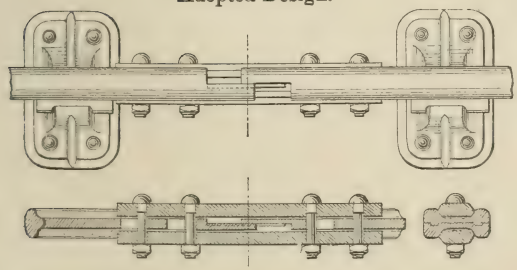
Figs. 18.



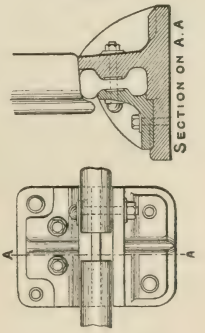
Figs. 19.



Figs. 20.
Adopted Design.



Figs. 21.



road over a viaduct—and further, to bear out some other statements, the Author would quote an extract from a letter from the Chief Engineer of the North British Railway, dated 12th October, 1891, on the working of the road as laid on the New Tay Viaduct after more than three-and-a-quarter years' trial.

"There is no appreciable increase in the cost of maintenance of the road.

"There is no vibration on the bridge sufficient to disturb the ballast in the troughs, and the number of slack fish-bolts is no greater on the bridge than on other parts of the line.

"The expansion rails and rockers work very smoothly and act very quickly.

"The road compares very favourably with a longitudinal-beam road.

"It is much more easily kept in line and level, repairs are more easily executed when required, and trains run smoother over a road with transverse sleepers than with longitudinal beams.

"No vehicle of any kind has, as yet, left the rails on the bridge."

The Paper is accompanied by 2 sheets of drawings from which the *Figs.* in the text have been prepared.

(*Paper No. 2635.*)

"Measurement of the Velocity of Air in Pipes."

By Bryan Donkin, Jun., M. Inst. C.E.

Having had occasion to use anemometers for measuring the velocity of air in pipes, the Author desired to determine, if possible, how much reliance might be placed on the results obtained, and the percentages of error with the different diameters of pipes used. Not being able to find any account of experiments where the air had been actually measured in bulk, a precaution which appeared to him necessary, he thought it desirable to undertake some himself. With this object he procured the loan of a small gas-holder, on which he carried out, in 1888–89, the experiments here described, in which he was greatly aided by his assistant, Mr. Bacon. The gasholder, kindly placed at his disposal by the Directors of the South Metropolitan Gas Company, was part of a small disused experimental gas-plant at Vauxhall, London. Their engineer, Mr. Carpenter, gave every facility in his power for the prosecution of the experiments.

Makers of anemometers, or air-speed recorders, generally calibrate their instruments by making them revolve at the end of a long lever, noting the circumferential speed of the apparatus, and comparing it with the speed of a rotary counter driven by the instrument. A certain constant number is thus found by experiment, and is added to the counter-readings, to make the record of the instrument agree with the distance actually traversed in the circular course. The question is, whether such a method of calibration gives correct results? During the tests, the instrument is driven through still air in a circular path; but in pipes, the air passes the anemometer in a direction approximately parallel to its axis.

The conditions in the two cases are not similar. In the trials here recorded, the air-holder was loaded with weights at the top, to give a pressure equivalent to between 3 and $6\frac{1}{2}$ inches head of water. After each experiment the holder was re-filled by pumping air under pressure by an exhauster driven by a small engine. Care

was taken, by previous testing, to prevent any leakages. The volume of the holder was calibrated by measuring its diameter very carefully at many points, the vertical fall being indicated on a scale. With a fall of 10 feet, the capacity of the holder was found to be 1,650 cubic feet, and, corrected for 3-inch water-pressure, 1,662 cubic feet, the mean internal diameter being 14,494 feet. From the holder the air was passed to the straight pipe in which the anemometer was fixed. The time, five to seven minutes, occupied in the descent of the holder through this 10 feet was carefully measured by two observers with stop-watches, as it passed two given points, A and B, 10 feet apart; the counter of the anemometer being started and stopped by signals as it passed these points. The temperature of the air passing through the pipes and that of the atmosphere were observed, and the pressure of air in the holder in inches head of water. The area of the pipe, in square feet, being known, and the quantity of air delivered in cubic feet per minute being ascertained, the velocity in the pipe was determined by dividing the latter quantity by the former.

The difference of the readings of the anemometer at start and finish were shown by its counter in feet per minute, plus the correction given by the maker for the instrument. Thus, the actual speed of the air through a given pipe, calculated in feet per minute from the volume of holder, was compared with the speed given by the instrument. The variation, or percentage of difference, between the speed in the pipe ascertained from the holder and that given by the anemometer, for the different diameters of pipes, was determined in the several experiments. In many cases the anemometer was purposely placed touching one side, or the top of the pipe under test, but was usually in the centre. A piece of perforated zinc was generally used, as a baffle, to direct the whole body of the air more evenly through the pipe, and was placed about 6 feet in front of the anemometer. The latter was fixed inside the pipes, about 2 feet from the free-discharge end. The velocity of descent of the holder was limited by its weight and by the area of its 6-inch exit-pipe. The experiments were mostly made with ordinary rough and rusty cast-iron gas-pipes, between 8 inches and 24 inches diameter, and between 9 feet and 12 feet long, but in one trial a zinc pipe 8 inches in diameter was employed. The trials were varied by increasing the weight put upon the top of the holder, to give additional velocity in the different pipes used. The ordinary weight was about 2,583 lbs. When it was desired to increase the pressure,

extra weights, equal to 2,468 lbs., were put on the top. In the latter case the addition of the two figures shows the total weight used. During some of the experiments Professor Kennedy, F.R.S., Professor Unwin, F.R.S., and the late Mr. Whipple, of Kew, were present, and the Author had the advantage of their criticisms.

The anemometer used throughout the trials was new, and by one of the best makers. The blades were of aluminium, and the axis worked in agates, as usual. Its outside diameter was $2\frac{3}{4}$ inches, and it was firmly fixed inside the pipe by a thin upright, $\frac{3}{8}$ inch in diameter, bolted to the bottom of the pipe. For stopping and starting the counter at the moment when the holder passed the two points on the vertical scale, a special engaging and disengaging tackle was used, worked by a lever outside the pipe. The Author's own anemometer was employed in nearly all the experiments, but trials were also made with one lent by Professor Unwin; the results were practically the same. The maker's correction of 30 to the number of revolutions, or velocity in feet per minute in the pipe, has of course been added. The front of the anemometer was fixed in each pipe at right-angles to the air-current, and care was taken that the pipe was not stopped in any way. The duration of each experiment was governed by the time of the descent of the holder with the pipes under test, and varied from 5 to $7\frac{1}{4}$ minutes. A possible error of a second might arise during the running, start, and stop of each experiment; or, say, two seconds error, which would be equal to about 1 per cent. The time-error may therefore be taken at between 1 and 2 per cent. The calculations of the contents of the holder and the area of the pipes are probably within 2 per cent. of the truth.

Six experiments were made (Nos. 14 to 19), with the free end of a 12·1-inch diameter pipe, blocked up with wood pierced with a hole, in the centre of which the anemometer was placed. The results were as follows:—The pipe being blocked up with this disk of wood, with a circular hole as described, $8\frac{1}{2}$ inches in diameter (area = $56\frac{3}{4}$ square inches), the anemometer-reading was found to be 23 per cent. in excess of that given by the calculated contents of the holder, with a water-pressure on the holder of 3 inches head, and a velocity of air through the hole of 610 feet per minute. The same experiment repeated with a $7\frac{1}{2}$-inch square hole (area = $56\frac{1}{4}$ square inches), showed the anemometer reading to be $24\frac{3}{4}$ per cent. in excess of the calculated speed as derived from the holder.

This method of measuring air by the anemometer cannot therefore be considered accurate.

A summary of the experiments is given on pages 350 and 351 for pipes 8, 10, 12, 14, 18, 20, and 24 inches in diameter, at two different water-pressures, viz., 3 inches and 6½ inches head in the holder.

The speeds of air varied in the centre of the pipes between 73 and 690 feet per minute. It will be seen that with the lower pressure (3 inches head), and with the anemometer fixed in the centre of the pipe, and without baffle, the anemometer speeds in feet per minute are nearly always faster than the calculated speeds. The percentage, however, varies in the different pipes between 14½ per cent. fast in the 8-inch pipe and 7½ per cent. fast in the 18-inch pipe. With the 24-inch pipe the anemometer reading was 13½ per cent. slow with 3 inches head, but only ⅓ per cent. fast with 6½ inches. The effects of inserting a disk of perforated zinc, called a baffle, some feet in front of the anemometer, may be seen in the Table. In pipes of certain sizes, the baffle seems to bring the anemometer and calculated holder-readings more nearly together. With the 24-inch pipe and the higher pressure only, the anemometer, at the centre of the pipe, practically agrees with the holder-readings. The percentage of error of the anemometer is also given, when the instrument was placed quite near to the side or to the top of the pipes; in a 14-inch pipe, the percentage of error is very small. The effect of painting a pipe inside is shown by the difference in the anemometer-speeds with the instrument at the sides of an 8-inch pipe, causing the anemometer to go about 3⅓ per cent. faster than when the pipe was rusty. The paint did not, however, affect the velocity of the anemometer if placed at the centre of the pipe, as might be expected.

The practical conclusion to be drawn from these experiments seems to be that anemometers for the measurement of velocities of air in pipes of these diameters should be used with great caution. It will be seen that the percentage of error is not constant, and varies considerably with the diameter of the pipes and the speeds of air. A baffle, on the whole, is advisable.

Probably a simpler and more accurate way of arriving at the quantity of air delivered by a given pipe is the following:—A small thin bent brass pipe, about $\frac{3}{16}$ inch in diameter, is held with its open end facing the current of air, and is connected by a rubber pipe to an ordinary U water-gauge. The mean water-pressure over the whole area can thus be carefully obtained. The mean head of water being given, the speed of air can easily be calculated by the well-known formula, or taken from a Table;

as, with a given water-pressure, there is a corresponding speed of air. This velocity, multiplied by the area of the pipe, will then give the quantity required. The total area should be divided into, say, ten equal parts, the pressure carefully taken in the centre of each, and the mean thus obtained. The pressure is obtained by a delicate gauge, indicating head to $\frac{1}{10}$ millimetre of water-pressure when required. With an anemometer in pipes, this is more difficult, and takes a much longer time. Putting a $2\frac{3}{4}$-inch anemometer into the centre of, say, a 24-inch pipe, can hardly be expected to give the true mean velocity of the air in motion. This, however, has frequently been done, and the Table shows the errors likely to arise from such a course.

SUMMARY OF EXPERIMENTS ON VELOCITY OF AIR IN CAST-IRON PIPES BETWEEN

Number of Experiments.	Internal Diameter of Pipe.	Position of Anemometer in Pipe.	Water-Pressure in Holder (Mean).	Time of Descent of Holder.	Temperature of Air.	
					Emitted from Pipe.	Atmospheric.
	Inches.		Head in Inches.	Minutes.	° Fahrenheit.	° Fahrenheit.
1–2–3	8	At centre	3·0	6·9	60·0	63·0
4–5–6	8	At side	3·0	6·93	57·0	62·0
94–95	$10\frac{1}{8}$	Centre	3·12	6·375	38·0	38·0
96·97	$10\frac{1}{8}$	Top	3·12	6·36	38·0	40·0
98–99	$10\frac{1}{8}$	,,	3·12	6·40	38·0	40·0
101–102	$12\frac{1}{10}$	Centre	3·12	6·42	39·5	39·5
8–9	$12\frac{1}{10}$	,,	3·0	6·83	70·0	70·0
10–11–12	$12\frac{1}{10}$	Side	3·0	6·78	$67\frac{1}{2}$	67·0
86–87	$14\frac{1}{10}$	Centre	$3\frac{1}{8}$	6·66	37·0	38·0
92–93	$14\frac{1}{10}$	,,	$3\frac{1}{8}$	6·61	37·0	39·5
88–89	$14\frac{1}{10}$	Top	$3\frac{1}{8}$	6·66	37·0	$38\frac{3}{4}$
90–91	$14\frac{1}{10}$	,,	$3\frac{1}{8}$	6·62	37·0	39·0
78–79	$14\frac{1}{10}$	Centre	6·5	4·9	$40\frac{1}{4}$	$39\frac{3}{4}$
84–85	$14\frac{1}{10}$	,,	6·5	4·91	41·5	40·0
80–81	$14\frac{1}{10}$	Top	6·5	4·88	42·0	41·0
82–83	$14\frac{1}{10}$	,,	6 5	4·89	$41\frac{1}{2}$	40·0
32–33	$17\frac{7}{8}$	Centre	3·0	6·82	73·0	$71\frac{1}{2}$
34–35	$17\frac{7}{8}$	Side	3·0	6·81	75·0	73·0
68–69	20	Centre	6·5	4·93	38·0	$35\frac{1}{2}$
74–75	20	,,	6·5	4·89	41·0	38·0
70–71	20	Top	6·5	4·88	39·0	36·0
72–73	20	,,	6·5	4·87	41·0	37·5
38, 39, 40	24	Centre	3·1	7·19	58·0	59·0
47–48–49	24	,,	3·1	7·2	45·0	46·0
42–43–44	24	Top	3·1	7·2	59·0	58·0
50–51–52	24	,,	3·1	7·2	46·0	47·0
58–59	24	Centre	6·5	4·9	$44\frac{1}{2}$	$45\frac{1}{4}$
66–67	24	,,	6·5	4·85	$45\frac{3}{4}$	$48\frac{1}{2}$
60–61	24	6 inches above centre	6·5	4·9	44·0	$45\frac{1}{4}$
62–63	24	Top	6·5	4·9	44·0	$45\frac{1}{2}$
64–65	24	,,	6·5	4·86	45·5	$47\frac{1}{2}$
25–26–27	$8\frac{5}{32}$	Centre	3·0	6·76	64·0	66·0
28–29–30	$8\frac{5}{32}$	Side	3·0	6·87	$65\frac{1}{2}$	69·0

8 INCHES AND 24 INCHES IN DIAMETER, AT TWO DIFFERENT PRESSURES.

Velocity of Air.		Per cent. of Error of Anemometer, assuming Holder to be correct.		Remarks.—Baffle means a Sheet of Perforated Zinc. Length of Pipes—9 feet to 12 feet. Capacity of Holder for 10 feet drop = 1,662 cubic feet for 3 inch pressure. All with Mr. Donkin's Anemometer 2 feet from the end of the Pipe.
By Anemometer + 30.	Calculated from Holder.	No Baffle.	With Baffle.	
Feet per Minute.	Feet per Minute.	Per Cent.	Per Cent.	
790·0	690·0	14·5 fast	..	Rough pipe.—Experiments 20–21 with same pipe painted inside; error was practically same, or 14·3 per cent. fast.
755·5	686·6	10·0 „	..	Rough pipe.—Experiments 23–24 with same pipe painted inside; error was 13·3 per cent. in excess of holder. Effect of paint is here seen.
501·7	448·6	11·8 „	..	Inside of pipe rough.
503·7	450·5	11·8 „	..	„ „
484·5	445·9	..	8·6 fast	„ „
504·1	443·7	..	13·6 „	„ „
339·0	305·0	11·1 „	..	„ „
327·0	307·0	6·5 „	..	„ „
247·2	230·1	..	7 4 „	„ „
264·3	231·8	14·0 „	..	„ „
233·1	230·1	..	1·3 „	„ „ Very nearly right.
237·7	231·4	2·7 „	..	„ „ „ „
349·7	315·7	10·7 „	..	„ „ Higher air-pressure in holder. All the above experiments at about the same pressure.
337·3	314·6	..	7·2 „	Inside of pipe rough.
323·3	316·8	2·0 „	..	„ „ Very nearly right.
334·2	315·7	..	5·8 „	„ „
150·5	140·0	7·5 „	..	„ „ Lower pressure.
126·0	140·0	10·0 slow	..	„ „ „ „ Anemometer slower than holder for first time.
165·7	155·9	..	6·2 „	Inside of pipe rough. Higher pressure.
172·0	157 3	9·3 fast	..	„ „ „
161·9	157·5	..	2·8 „	„ „ „ Two methods agree practically.
155·2	157·7	1·58 slow	..	„ „ „
63·5	73·6	13·66 „	..	„ „ Lower pressure.
53·92	73·41	..	26·55 slow	„ „ „ „
50·12	73·40	31·85 „	..	„ „ „ „
44·4	73·5	..	39·6 „	„ „ „ „
104·9	108·9	..	3·67 „	„ „ Higher pressure.
110·3	110·0	0·27 fast	..	„ „ „ Two methods agree.
108·6	108·9	..	0·27 „	„ „ „ Two methods agree.
99·9	109·1	..	8·43 „	„ „ „ „
97·2	109·8	11·47 slow	..	„ „ „ „
746·7	677·7	10·2 fast	..	Zinc pipe.—All above with cast-iron pipes. Lower pressure.
704·0	666·7	5·6 „	..	

(*Paper No. 2621.*)

"Strength of Concrete Slabs."

By Sidney Richard Lowcock, Assoc. M. Inst. C.E.

This Paper gives the results of a series of tests made by the Author to determine the strength of cement concrete slabs made with varying proportions of cement, in order to ascertain their suitability for covering an underground trench exposed to ordinary road-traffic. The slabs were made with Portland cement and ground clinker obtained from furnaces which burned ash-pit refuse.

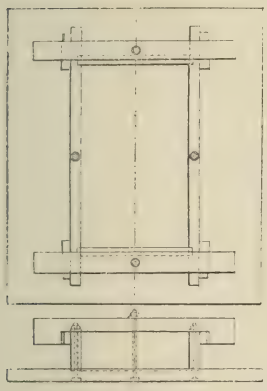
The composition of the cement used was:

	Per cent.		Per cent.
Volatile matter . . .	0·50	Lime	58·20
Silica { insoluble 4·60 / soluble 17·10 } .	21·70	Magnesia	1·44
Alumina	11·15	Sulphuric acid . . .	1·30
Oxide of iron	4·85	Alkalies	0·85

Its weight, when filled into a measure from a hopper with a fall of 1½ feet, was 112 lbs. per striked bushel. Its fineness was such that when sifted through a sieve having 2,500 meshes to the square inch, the residue was 12·8 per cent. Its tensile strength was tested, in a Bailey shot machine, on briquettes of a sectional area of 1 square inch, the stress being applied at a rate of 100 lbs. in 22½ seconds. The briquettes were placed in water 24 hours after being gauged; and, when tested after 7 days' immersion, exhibited a tensile strength (as an average of seven tests), of 665 lbs. per square inch. The clinker was broken by being crushed once in a mortar-mill with two rollers, and was then passed through a screen having ¾-inch meshes, and was thoroughly washed with clean water. This washing requires to be carefully done; as otherwise, it was found that the concrete swelled and blew after setting. The materials were mixed in varying proportions, three sets of slabs being made: one set with 4½ parts of clinker to 1 of cement; one set with 6 parts of clinker to 1 of

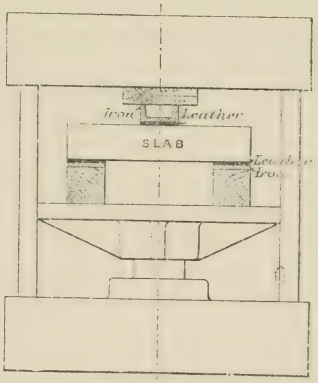
cement; and one set with 8 parts of clinker to 1 of cement. In those made with $4\frac{1}{2}$ parts to 1, it was found that there was sufficient fine material to properly fill the interstices, though it was not so in those made with 6 parts to 1. When 8 parts of clinker to 1 of cement were used, the clinker was made up of 6 parts broken to pass $\frac{3}{4}$-inch mesh, and 2 parts ground to the fineness of coarse sand, the clinker being if anything rather in excess. The concrete was then filled into wooden moulds, *Fig. 1*, and well rammed. The moulds were greased at the joints to prevent leakage; and the bottom was sanded and the sides and ends were greased to prevent the concrete from adhering to them. As soon

Fig. 1.



MOULD FOR SLABS.

Fig. 2.



HYDRAULIC PRESS.

Scale $\frac{3}{8}$ inch = 1 foot.

as the concrete was set, the wedges were knocked out and the sides and ends were removed.

The slabs thus made were found to be all solid and practically homogeneous. Each set of slabs was made in three sizes: 1 foot 9 inches by 1 foot 6 inches by 4 inches; 2 feet 6 inches by 1 foot 6 inches by 6 inches; and 3 feet 3 inches by 1 foot 6 inches by 9 inches, respectively. These were kept dry, some for 14 and some for 21 days, and were then tested to destruction by means of hydraulic pressure applied as shown in *Fig. 2*, the pressure being applied by a hand-pump in about two minutes. The slabs were supported at each end by oak balks faced with $\frac{3}{4}$-inch iron plates, strips of leather of the width of the bearings and $\frac{5}{16}$-inch thick being placed between the iron plates and the slabs. The distance apart of the bearings varied, being so arranged that the smallest-

sized pieces had a bearing at each end of $4\frac{1}{2}$ inches, and the largest sizes 6 inches. The pressure was applied along the centre-line of each slab by a channel-iron 6 inches wide with a packing-strip of leather between the channel-iron and the slab. With one exception, no sign of fracture appeared before they broke down. The plane of fracture was generally fairly through the middle of the slab.

The Table in the Appendix gives the results of the tests and the value of K, the coefficient of rupture, calculated from the following formulas :—

Supports 12 inches apart, load on centre 6 inches of slab, $K = \frac{3\,L\,W}{16\,B\,D^2}$;

„ 18 „ „ „ „ 6 „ „ , $K = \frac{5\,L\,W}{24\,B\,D^2}$;

„ 27 „ „ „ „ 6 „ „ , $K = \frac{2\,L\,W}{9\,B\,D^2}$;

where L = span, W = breaking weight in pounds, B = breadth, and D = thickness of slab. The results obtained with the slabs made of $4\frac{1}{2}$ parts of clinker to 1 of cement are fairly consistent; and the variation in the other tests is, in the Author's opinion, due to the fact that, in the 6 to 1 slabs, there was too little, and in those made in the proportion of 8 to 1, too much, fine material. A rectangular block of concrete $6\frac{3}{4}$ inches by $3\frac{1}{4}$ inches by 4 inches, cut from the outside of the broken part of block A, and tested for crushing-resistance, broke down under a pressure of 1,120 lbs. per square inch. The weight of this concrete, $4\frac{1}{2}$ to 1, 15 days old, was 118 lbs. per cubic foot. The Author is indebted to Professor Henry Robinson, M. Inst. C.E., for permission to communicate the results of the foregoing tests.

It was subsequently decided to try the effect of crushed blast-furnace slag instead of clinker, and one slab made from this slag broken to pass a $\frac{3}{4}$-inch mesh, without the addition of any fine material, in the proportion of $4\frac{1}{2}$ of slag to 1 of cement, was tested by a dead weight with the following result: Cement used—weight, 120 lbs. per bushel; fineness, 7·8 per cent. residue left on a sieve having 2,500 meshes to the square inch; tensile strength, tested in the manner before described, 449 lbs. per square inch; slab 3 feet 3 inches long by 2 feet $5\frac{1}{2}$ inches wide by $4\frac{1}{2}$ inches thick, kept for fifteen days in air; supports 27 inches apart; load applied on centre 6 inches of slab,—breaking weight, 2,518 lbs.; time taken in applying weight, half an hour; this gives K = 25·3 lbs. The coefficient is lower than that obtained with clinker-slabs made in the same proportions; but this is due partly to the addi-

tional length of time taken in applying the load, and partly to the inferior strength of the cement used.

With the object of comparing the strength of the two kinds of slab under similar conditions, the following tests were made—the slabs being placed in position under conditions as nearly as possible those in which they were intended to be used: A slag-slab, precisely similar to that last mentioned, was supported on two walls of concrete 27 inches apart, formed in a trench excavated in the ground, the slab being covered with 2 feet of earth well rammed to the ground-level. The weight was then applied on an area of 9 inches by 6 inches, the larger dimension being in the direction of the breadth of the slab. The breaking-weight was 11,865 lbs.; the slab broke across the centre, and the time occupied in applying the load was one hour. Assuming that the pressure was distributed by the earth-filling uniformly over the whole surface of the slab, K = 67 lbs. A clinker-slab, 3 feet 3 inches long by 2 feet 2 inches wide by $6\frac{3}{4}$ inches thick, was made of $4\frac{1}{4}$ parts of broken and washed clinker, without the addition of any fine material, and one part of the same Portland cement as that used in making the slag-slabs; but when tested it was 35 days old, compared with 15 days in the case of the latter. This clinker-slab was tested in the same trench and in the same way as the slag-slab, and broke with a weight of 9,567 lbs., thus giving K = 27·2 lbs.; the time taken in applying the load was one hour.

These experiments showed that the slag-slab 15 days old was 2·46 times as strong as the clinker-slab 35 days old. The Author considers that these latter tests are not completely comparable; but they could only be made as opportunity offered, at intervals during the prosecution of other work.

The communication is accompanied by a tracing, from which *Figs. 1* and *2* have been prepared.

APPENDIX.

Results of Tests.

Slab.	Dimensions.	Distance apart of Supports.	Breaking Weight.	Coefficient of Rupture = K.	Averages.	Proportions of Concrete.	Number of Days Kept.
	Ft. Ins. Ft. Ins. Ins.	Inches.	Lbs.	Lbs.	Lbs.		
A	1 9 × 1 6 × 4	12	5,081	39·7			
B	2 6 × 1 6 × 6	18	5,986	34·6	35·4	$4\frac{1}{2}$ to 1	15
C	3 3 × 1 6 × 9	27	7,745	31·8			
D	1 9 × 1 6 × 4	12	6,518	50·9			
E	2 6 × 1 6 × 6	18	9,946	57·5	52·1	$4\frac{1}{2}$ „ 1	21
F	3 3 × 1 6 × 9	27	11,648	47·9			
G	1 9 × 1 6 × 4	12	2,755	21·5			
G′ [1]	1 6 × 1 0 × 4	12	1,747	20·4			
H [2]	2 6 × 1 6 × 6	18	1,400	8·1			
H [3]	2 6 × 1 6 × 6	18	1,098	6·3	22·9	6 „ 1	14
I	3 3 × 1 6 × 9	27	4,939	20·3			
I′	3 3 × 1 6 × 9	27	7,282	29·9			
I″	3 3 × 1 6 × 9	27	5,466	22·5			
J [3]	1 9 × 1 6 × 4	12	1,322	10·3			
K	2 6 × 1 6 × 6	18	2,262	13·1	19·8	6 „ 1	21
L	3 3 × 1 6 × 9	27	6,474	26·6			
M [4]	1 9 × 1 6 × 4	12	650	5·1	5·1	8 „ 1	14
N	1 9 × 1 6 × 4	12	1,187	9·2			
O	2 6 × 1 6 × 6	18	739	4·2			
P	3 3 × 1 6 × 9	27	1,994	8·2	7·6	8 „ 1	21
P′	3 3 × 1 6 × 9	27	2,106	8·7			

[1] Part of slab which broke in getting out of mould.
[2] Affected by frost
[3] Broken in getting out of mould } Not included in averages.
[4] Not dry through.

(*Paper No. 2598.*)

"Haltahaut Cut."

By JOGINDRA NATH GHOSH, Assoc. M. Inst. C.E.

(*Abstract.*)

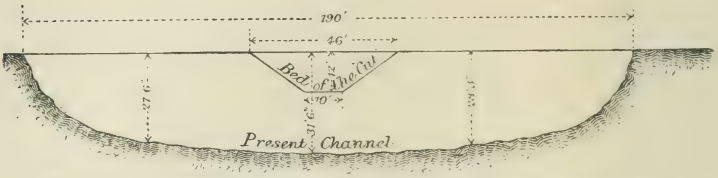
THIS work consists of a navigable channel, 2,260 feet in length, cut through a neck of land which separates the Rivers Pandop and Kyrabad—two of the many tidal channels that intersect the deltaic formation near Barisal at the mouths of the River Ganges.

Tidal observations were made at the ends of the proposed cut during three days of spring-tides and three days of the succeeding neap-tides; and from the relative water-levels thus obtained, the mean velocities in the channel were determined, upon the assumption that its dimensions would be: bottom, 10 feet wide, 5 feet below low-water level; slopes, $1\frac{1}{2}$ to 1. The mean velocity was calculated at short intervals throughout the periods of the tides under observation by means of an expression of the form $v = c\sqrt{ri}$. From the results it was inferred that, during spring-tides, the velocity would be between 2 and 4 feet per second for nearly one-half the period, between $1\frac{1}{2}$ and $1\frac{3}{4}$ foot per second for one-fourth of the period, and for the remaining fourth, slack water; and, during neap-tides, between 2 and 4 feet per second for more than half the period, falling to between 1 and 2 feet per second for the remaining half. These investigations removed all doubts as to the cut becoming silted up. On the other hand, it was anticipated that the channel would become enlarged by the scouring action of such strong currents upon the banks. No gauge-readings were taken during the rains, as the rise of the river at that season and the velocity in the cut would naturally exceed that during the cold weather. The excavation of the channel was begun on the 6th of January, 1888, and the work was finished before the commencement of the rainy season. As manual labour only was employed, some difficulty was experienced in excavating below the low-water line. The channel, which it was at first thought would be kept open with

difficulty, has worked successfully, and, on the 10th July, 1888, a surface-velocity of 9 feet per second was measured in it.

The sketch, *Fig. 1*, shows the cross-sections of the originally-

Fig. 1.



Cross Sections of the "Cut" and the Channel as enlarged.

constructed cut, and of the channel as subsequently enlarged by natural scour. The cost of the excavation amounted to Rs. 4,513.

The Paper is accompanied by 3 drawings, from one of which *Fig. 1* is reproduced.

OBITUARY.

GEORGE GRANVILLE WILLIAM SUTHERLAND LEVESON GOWER, K.G., third DUKE OF SUTHERLAND, and possessor of numerous other titles of nobility, was born on the 19th of December, 1828. The taste for engineering which led to his connection with this Institution, and which in other circumstances might have acquired for him a high position as a professional man, showed itself very early in life. It was confirmed and developed by his official connection with the London and North Western Railway. Owing to substantial assistance rendered by the first Duke of Sutherland in raising the capital for the Liverpool and Manchester Railway that nobleman was granted the right to nominate three of the Directors of the Company. When the Liverpool and Manchester, the London and Birmingham, and the Grand Junction Railways were amalgamated as the London and North Western Company, the Act of Incorporation specially provided that the Dukes of Sutherland should always have the right to nominate one Director. The subject of this notice was nominated by his father in 1852 and continued to serve until the end of his life. In this way in the early days of his directorship he came in contact with Mr. J. E. McConnell, then Locomotive Superintendent, and spent much of his time in the shops at Wolverton, it even being asserted that he served as a pupil of Mr. McConnell. Be this as it may, it is certain that he became a highly competent mechanician, thoroughly conversant with the design and construction of steam-engines and often driving locomotives as a recreation.

On succeeding to his inheritance in 1861, the Duke of Sutherland acquired free scope and ample means to put into practice his ideas as to the application of engineering resources to the improvement of his estates. Undoubtedly one of the greatest enterprises of estate-management ever undertaken by a private individual was the celebrated reclamation in Sutherlandshire, where the Duke owned 1,177,000 acres. The work had been begun by his predecessors, but their achievements were perfunctory compared with the results obtained from the heroic and sustained attack made by him on the stubborn, inhospitable desert of rock and morass. The history of the work is fully detailed in an elaborate Paper by

Mr. Charles Gay Roberts, entitled "Sutherland Reclamation," which appeared in the Journal of the Royal Agricultural Society.[1] A general outline of the results obtained is all that can be given here, but it may be recorded that in the thirty years from 1853 to 1882 a sum of £900,000 was spent on estate works at Dunrobin and on the improvement of waste lands at Lairg and Kildonan. It was not, however, until 1873 that the great work of reclamation was practically begun. A tract of land about 6 miles from the railway-station at Lairg was fixed upon, a roadway sufficient to bear large traction-engines was made, and about 250 acres of land were ploughed up, the implements being two 16-HP. traction-engines and a plough specially designed for the purpose by Messrs. John Fowler and Co., of Leeds, on plans in a great measure furnished by the Duke. The special features of the plough were the provision of a flat iron disk, about 3 feet in diameter, with a cutting-edge serving to divide the grass or roots on the surface, and an iron hook at the end penetrating deep enough to tear out any large boulders or roots passed over by the fore parts of the plough. In the case of roots or stones too firmly imbedded for this treatment, blasting was had recourse to. Single trees of good size, or clumps of smaller ones, were torn up bodily, chains being passed round their trunks and an attachment made to the ploughing-engine, which was then set in motion at full speed. To enable the reclamation to be carried out at a quicker rate a new plough on a simplified plan was subsequently used. This was fitted with three large wooden wheels, or rollers, one running on the unbroken land, the others passing alternately over the portion turned up, and partially rolling and compressing it. In front at each side was a flat coulter, instead of a revolving disk, and the fore part was bevelled so as to pass over any large stone or other obstruction. A peculiar form of sledge, attached to a windlass by wire-rope and drawn backwards and forwards, was used for removing from the land the stones and boulders, which sometimes amounted to 200 tons per acre. By these means over 2,000 acres of arable and 9,000 acres of pasture land were reclaimed in less than four years. In the case of arable land the cost was originally estimated at £24 per acre; but, taking drains, roads, farmsteads and houses into account, it amounted to over £30 per acre. Even at that cost it was hoped that, as a commercial speculation, the undertaking would eventually pay from 2 to 3 per cent. on the capital sunk in the works. But bad

[1] Vol. xv. Second Series, p. 397.

seasons and the crofter-agitation have hitherto prevented the reclamations being a commercial success.

The results achieved at Lairg encouraged the Duke to embark upon a similar undertaking at Kildonan, the object of which was to increase the breadth of land not only for cereals but for green crops and esculents, so as to provide winter pasturage for sheep and food for the growing population of the district. The works were commenced in 1877, the ground selected including a range of moors of some 10,000 acres. The land reclaimed was formed into farms of all sizes, from 50 to 500 acres; sloping grounds along the railway were laid out for smaller tenants, and the sheep-farms and their mountain pasture were connected with the larger allotments. In this way new fields of industry were provided for both small and large capitalists, and the sheep-farmer, enabled to feed his sheep at home instead of sending them to the low country during winter, could put a larger number on the hills and thus increase the supply for the general market. By means of improved machinery the cost of these works was reduced to about £20 per acre.

Although the Sutherland reclamations form the most important contribution of the late duke to that task of directing the great sources of power in Nature for the use and convenience of man which it is the function of this Institution to foster, they by no means comprised all his labours in the field of economical progress. The extension of the railway system to the extreme north of Scotland was largely due to him. The original Highland Railway, opened in 1863, only reached from Dunkeld to Forres. This was subsequently continued to Bonar Bridge, which seemed at one time likely to remain its northern limit, owing to the Company having got financially into low water. But the Duke's public spirit induced the construction of the Sutherland Railway from Bonar Bridge to Golspie, for which purpose he provided nearly one-half the capital. The extension from Golspie to Helmsdale, 17 miles long, was constructed solely by him, at a cost of £72,000, and bore the title of "The Duke of Sutherland's Railway." He immediately afterwards promoted and became the largest shareholder in the Sutherland and Caithness Railway from Helmsdale to Wick and Thurso, 66 miles in length, which was opened in 1874. These three lines—the Sutherland, the Duke of Sutherland's, and the Sutherland and Caithness—were incorporated with the Highland Railway in 1884. The amount of stock taken by the Duke, from first to last, in the lines now forming the Highland

Railway, reached the total of £350,000. By this enlightened enterprise the North of Scotland has made a material advancement in prosperity, which, without his help, might not have been attained within the next generation. The Duke was a Director of the Company for upwards of thirty years and always took an active interest in the management of its affairs, being present at a Board Meeting held a fortnight before his death.

It will be seen from the foregoing that the Duke of Sutherland was a railway magnate of the first degree; but he was more than this. His grasp of economical subjects enabled him to appreciate to the full the power of the iron road as a civilizer, and his advocacy of this means of intercommunication was systematic and practical. He was one of the promoters of the original Mont Cenis (Summit) Railway, on which Mr. Fell's system of locomotives was adopted, and which worked successfully for several years preceding the opening of the tunnel. Further East, he was a warm supporter of the late Sir W. P. Andrew's project for a line down the Euphrates Valley, forming part of a proposed through communication from Constantinople to the head of the Persian Gulf and on to India, after the Berlin Conference of 1878 seemed upon the point of obtaining a concession for the construction of this railway by British capitalists. However, the interest in this scheme, momentarily resuscitated by the Russo-Turkish war, languished and finally became dormant. Other proposals he espoused in the same direction related to the Southern Mahratta and the line now known as the West of India Portuguese Railway, which affords communication between Goa and the railway system of the rest of India. Still further East he advocated the cause of railways in China, and was connected with the pioneer line from Shanghai to Woosung, of which Mr. R. C. Rapier was the moving spirit.[1] In connection with Eastern communication generally, the Duke of Sutherland took up a strong and patriotic position, warmly supporting the government of Lord Beaconsfield in the purchase of the Suez Canal shares. He had an intimate acquaintance with Egypt and possessed a stake in the prosperity of the country in respect of the extensive irrigation-works undertaken under British auspices. He was also connected with the Alexandra Waterworks.

The Duke was an enterprising colliery owner and introduced a new method of working into his Staffordshire collieries which was the subject of serious investigation among mining engineers. In

[1] Minutes of Proceedings Inst. C.E., vol. lix. p. 274.

January 1875 a large party of engineers, ironmasters and colliery proprietors, visited the Florence Colliery and "appeared to be of opinion that it would be impossible to improve upon the system of sinking adopted by the Duke of Sutherland." [1] He also opened a pit at Brora, near Dunrobin, for supplying coal for the portable engines used at the Sutherland reclamation and for the locomotives on the Duke's railway. It was in connection with the latter that he aroused the enthusiasm of a navvy, who is said to have exclaimed, "There, that's what I call a real dook! Why, there he is a-driving of his own engine on his own railroad, and a-burning of his own blessed coals!"

One of the Duke of Sutherland's avocations, which at one time gave rise to some amused comment amongst Londoners, was his liking for serving as an amateur fireman. In his younger days, when Marquis of Stafford, he made a point of being present at most of the great fires in London, and at any practical test of fire-brigade efficiency.

On the part played by the Duke of Sutherland in social and political life it is not expedient here to enlarge. It will suffice to say that until of late years, when he withdrew a good deal from society, his hospitality was profuse and magnificent; Stafford House indeed achieved an almost unique position, insomuch that the lionizing of distinguished visitors and men of the day, from crowned heads to African explorers, was deemed incomplete unless an entertainment at that princely abode formed part of it. It was also a centre of philanthropic and socio-scientific activity scarcely second to the Mansion House itself. Among the best known movements started by the Duke were the Stafford House Committees for the relief of the sick and wounded in the Turkish and Zulu wars, which acted continuously from 1877 to 1880, and were the means of alleviating an incalculable amount of suffering among the victims of those campaigns.

The Duke of Sutherland seemed to be destitute of political ambition. His only prominent appearance on the platform was in 1878 on the occasion of a lecture by Mr. (now Sir Algernon) Borthwick, M.P., advocating, if necessary, British interposition to prevent the Russian occupation of Constantinople, when the Duke, as Chairman, delivered a menacing "hands-off" speech which caused an immense sensation and was probably a factor of influence in determining the firm position subsequently taken up by Lord Beaconsfield's government on this question.

[1] The *Engineer*, January 15, 1875.

The Duke was a great traveller, and a prolonged visit he made to the Western States of the North American Union in 1881, in company with a large party of friends, was deemed of sufficient importance to be attended by several newspaper correspondents. It is believed that his death, which occurred on the 22nd of September, 1892, after an illness of only a few days, was remotely connected with these extensive journeyings, as it was remarked that towards the close of his life he had lost much of the energy and activity which formerly characterized him.

The Duke of Sutherland, who was also a Fellow of the Royal Society, was elected an Honorary Member of the Institution on the 2nd of May, 1865. He was at one time a rather frequent attendant at the meetings in Great George Street, and latterly, when the monthly receptions by the President and Council were established, he was present at the one which inaugurated the custom.

JOHN BAILEY, fourth son of the late Mr. Hinton Richard Bailey, of Pittleworth, in the county of Hampshire, was born on the 31st of May, 1839, at Wallop, near Stockbridge, and was educated at a private school in Southampton. In 1857 he was apprenticed for five years to Messrs. Summers and Day, engineers and shipbuilders, of the Northam Ironworks, Southampton. The first part of that time he spent in the shops and the latter part in the drawing-office, engaged on work for the "Northam" and other large steamships, for the machinery of which the firm had the contract. On the completion of his apprenticeship he was employed from 1862 to 1864 in the drawing-offices of H.M. Dockyards at Devonport and Portsmouth.

In 1865 Mr. Bailey joined the firm of Courtney and Stephens, Engineers, of Dublin, in place of Mr. William Anderson, who had entered into partnership with Messrs. Easton and Amos, of London. The firm was then known as Courtney, Stephens, and Bailey, the place of the elder Mr. Courtney being taken by his son, and Mr. Bailey acting as chief engineering partner. During the nineteen years this connection lasted the firm carried out many important railway works, such as the construction of bridges, girders, cylinder-foundations, and signals, including Bailey's locking apparatus; in addition to the manufacture of land and marine engines, boilers, hydraulic machinery, and distilling-, brewing-, and milling-plant. The Midland Great Western, the Dublin, Wicklow and Wexford, the Great Southern and Western, and

the Great Northern of Ireland Railway Companies were among the chief customers of the firm. For the latter company Mr. Bailey carried out between the years 1876 and 1884 the following works in accordance with the plans prepared by Mr. W. H. Mills, the company's Chief Engineer:—Seville Place bridge, Dublin, with ten lines of way; a new iron roof for the goods warehouse at Navan; a water-tank at Cookstown; a public road over bridge at Lurgan; Dungannon footbridge; Sheriff Street bridge, Dublin, and Windmill Road bridge, Dundalk, each with four lines of way; Beragh footbridge; and girders for the booking hall of Amiens Street Station, Dublin; in addition to the principal part of the permanent way fastenings used on that line during the period in question.

Among other contracts carried out by the firm were:—The ironwork used in the lowering and widening of Essex Bridge, Dublin, designed by Mr. B. B. Stoney; Georges Dock swivel-bridge on the North Wall; the new roofs of Westland Row Station and various other works for the Dublin, Wicklow, and Wexford Railway Company; heavy girder and ironwork for the Great Southern and Western Railway Company's goods terminus at North Wall; the Nore Viaduct at Thomastown on the Waterford and Kilkenny Railway; floating swing-bridges at the Spencer Dock; the railway bridge over the River Inny, co. Westmeath; and the alteration of a rolling railway-bridge over the Shannon at Drumena, co. Leitrim, into a single-flap bascule: the three last works being carried out for the Midland Great Western Railway Company. The alteration of the bridge over the Shannon was made, under considerable difficulties, on a single line without stopping the traffic or diverting the railway. Mr. Bailey was also connected for several years with the Old Bawn Paper Mills at Tallaght, near Dublin, and was extensively employed as an expert witness in engineering law-suits.

In 1865 he was elected a Member of the Institution of Civil Engineers of Ireland, and served the office of President during the years 1879 and 1880. His Presidential Address,[1] delivered on the 14th of April, 1880, dealt with the progress of mechanical science and contained a review of recent important engineering works in all parts of the world. He had previously presented to that Institution the following Papers:—"Description of Captain Cole's (R.N.) Turrets, as fitted on board H.M.S. 'Royal Sovereign';"[2] "On Anderson's Patent Lock Arrangement for Railway Signals;"[3]

[1] Trans. Inst. C.E. Ireland, vol. xiii. p. 51.
[2] *Ibid.*, vol. viii. p. 118.
[3] *Ibid.*, vol. ix. p. 31.

"A 50-ton Masting-Sheers;"[1] and "A new kind of Locking-gear and Safety Facing-point."[2]

Mr. Bailey practically retired from business in 1884, and spent the remaining eight years of his life partly in England and partly on the Continent. He died at Brighton on the 5th of August, 1892, from peritonitis. Mr. Bailey possessed great energy and firmness of character which, combined with a kind and cheerful disposition, won him many friends. He married in 1866, Jane, daughter of the late Mr. William A. Summers, of Southampton. He was elected a Member of the Institution on the 5th of April, 1870.

CHARLES CHRISTISON BONE was born at Whithorn, Wigtonshire, on the 10th of November, 1844. Six years later his parents removed to Glasgow, where he studied at the Mechanics' Institution and in the engineering class of Professor Rankine at the University. In January 1859, he was articled to Messrs. Wharrie and Smith (now Messrs. Wharrie, Colledge and Brand) of Glasgow, with whom he remained until September 1866, giving evidence of great natural ability and taking full advantage of his position as a trusted assistant of the firm to acquire extensive knowledge of the details of the profession. On the 5th of October, 1868, he entered the service of the Glasgow Corporation Waterworks, under Mr. James M. Gale, the Chief Engineer. His first duty was to prepare contract drawings for works to pump $7\frac{1}{2}$ million gallons of water per day from the River Clyde for manufacturing purposes. These works were after some years' delay executed at a cost of about £80,000.

Mr. Bone remained in the service of the Glasgow Corporation Waterworks until the 8th of December, 1870, when he became principal assistant to Messrs. Shelford & Robinson of Westminster. During the two years he occupied that position he was engaged, amongst other things, on the construction of waterworks at Louth and Truro. He then entered the office of the late Mr. La Trobe Bateman, Past-President Inst. C.E., by whom he was employed on the Manchester Waterworks, and subsequently as Resident Engineer on part of the Batley Waterworks under Mr. G. H. Hill. On the latter work he very successfully laid a main of considerable length —17 or 18 miles—under great pressure.

[1] Trans. Inst. C.E., Ireland, vol. x. p. 25.
[2] *Ibid.*, vol. x. p. 153.

On the 1st of April, 1876, Mr. Bone re-entered the service of the Glasgow Corporation Water Commissioners as Assistant Engineer. Mr. Gale's time being in great part occupied with a considerable extension of the Loch Katrine scheme, Mr. Bone was placed in charge, as Resident Engineer, of the distribution of water to a population of 780,000, and designed and carried out all extensions and alterations within the area of distribution, including the placing of 140,000 of the population under Deacon's waste-water meter system. In 1886 the daily supply was about 42,000,000 gallons by gravitation and 2,500,000 by pumping, and the number of men employed under Mr. Bone's charge was about 270. Unfortunately, however, his lungs became seriously affected—so much so that in the summer of 1890 he decided to take a voyage to South America. He returned much improved; but in the following spring his health again broke down. He was granted six months' leave of absence in order to go to Beaufort West, South Africa—a resort for consumptive patients—where he died on the 16th of May, 1892.

Mr. Bone was an intelligent, careful and hard-working engineer, and in his constant intercourse with the Glasgow public and with the members of the Water Commission gained great respect and made many friends. He was elected a Member of the Institution on the 11th of January, 1887.

Sir JAMES BRUNLEES was born on the 5th of January, 1816, at the border town of Kelso, where his father was gardener and steward to the late Mr. Innes, agent to the then Duke of Roxburgh. At six years of age he was sent to the parish school and subsequently to the only private school in the town, which was kept by a Mr. Scott, under whom he made rapid progress, especially in arithmetic and elementary mensuration. He was taken from school at the age of twelve and put by his father to gardening and farm work with the idea that he should become a landscape gardener. About this time he came into contact with Mr. Alexander J. Adie, who was making frequent visits to Mr. Innes, in connection with road-surveys and other improvements on the Roxburgh estates. He accompanied Mr. Adie on this work and the useful assistance he rendered that gentleman was acknowledged by the presentation of a theodolite, with which young Brunlees afterwards made in the summer evenings a survey of Broomlands farm. On showing his plan, when finished, to Mr. Innes, he was

instructed to make a survey of the Duke's property. This he accomplished satisfactorily, and by working early and late saved in the course of time sufficient money to enable him to attend classes at the Edinburgh University for several sessions.

In 1838 Mr. Brunlees was engaged by Mr. Adie as an assistant on the construction of the Bolton and Preston Railway, now forming part of the Lancashire and Yorkshire system. His salary was £40 a year, and in order to qualify himself still further, he devoted all his spare time to study and took every opportunity of going over the works with the inspectors and of thus gaining a practical knowledge of details. He then obtained an appointment on the staff of Messrs. Locke and Errington and assisted in the laying out of the Caledonian line from Beattock to Carstairs and the branches to Edinburgh and Glasgow. On the completion of this work he became Acting Engineer, under the late Sir John Hawkshaw, to the Lancashire and Yorkshire Railway Company, which post he held for about six years. In 1850 he was Engineer for the construction of 36 miles of the Londonderry and Coleraine Railway in the north of Ireland. This involved the formation of an embankment across Rosse's Bay in the River Foyle,[1] which work was attended with considerable difficulty owing to the unusual depth and the treacherous nature of the alluvial deposit round the bay. In 1851 the Ulverstone and Lancaster Railway was incorporated, the object being to complete a direct line from Whitehaven and the west coast of Cumberland to the south of England. Mr. Brunlees was appointed Engineer, and the important sea-embankments and iron viaducts in Morecambe Bay, across the estuaries of the Kent and Leven, which he constructed for that railway, were described in Papers presented by him to the Institution in 1855 and 1858.[2] In these viaducts he introduced a novel form of pile as better adapted to the situation than the ordinary screw-pile.

The next work of Mr. Brunlees was the survey and construction of the São Paulo Railway, one of the important Anglo-Brazilian lines. This was placed in his hands at the beginning of 1856 by Baron de Mauá, the principal concessionnaire, and he was charged with the preparation of the plans and sections and of the report and estimates necessary for the organization of a company in England. Under the terms of the concession the line was to commence at Santos on the coast, pass through the city of São

[1] Minutes of Proceedings Inst. C.E., vol. xiv. p. 249.
[2] *Ibid.*, vol. xiv. p. 239, and vol. xvii. p. 442.

Paulo, and terminate at Jundiahy, a distance of about 88 miles. The preliminary surveys were made by Mr. D. M. Fox, who was sent out by Mr. Brunlees and who subsequently acted as principal Resident Engineer during the construction of the line. This work was described by Mr. Fox in a Paper read before the Institution in March 1870.[1] One of the chief difficulties was the construction of a first-class railway up the precipitous sides of the "Serra do Mar," which runs parallel to the sea-coast in a direction at right angles to that of the line and rises abruptly to a minimum height of 2,500 feet above the sea-level. It was not possible to lay out, within the limit of the prescribed capital, an ordinary locomotive line over the Serra. Mr. Brunlees determined therefore to adopt inclined planes with a gradient of 1 in 10, to be worked by stationary engines, and these planes are the distinctive feature of the railway. On the completion of the line he received from the Emperor of Brazil the Order of the Rose.

In 1865 Mr. Brunlees was appointed Engineer to the Mont Cenis Summit Railway, the concession for which, however, was to lapse on the opening of the Mont Cenis Tunnel line. The summit railway was 50 miles in length and connected St. Michel, the terminus of the Victor Emmanuel line in Savoy with Susa in Piedmont, the terminus of the railway system in the north-west of Italy. It was worked on the Fell central-rail system. A brief description of the line was given by the late Mr. Charles B. Vignoles in his Presidential Address to the Institution.[2] Amongst other railways for which Mr. Brunlees acted as Engineer in the course of his long career may be mentioned the Lynn and Sutton, and the Spalding and Bourn, now forming part of the Great Eastern and the Great Northern systems; the Solway Junction; the Cleveland Extension line in the North Riding of Yorkshire, with a viaduct of thirteen spans and 180 feet high over Skelton Beck; and, in conjunction with Mr. (now Sir) Douglas Fox, the Mersey; the Southport and Cheshire Lines Extension; the West Lancashire; and the Liverpool, Southport, and Preston Junction. The most important of these, the Mersey Railway, with its tunnel under the river between Birkenhead and Liverpool, was described by Mr. Francis Fox in a Paper presented to the Institution.[3] On the completion of the work in 1886 Mr. Brunlees and Mr. Douglas Fox, the joint engineers, received the honour of knighthood. In addition to these lines the following are some of the

[1] Minutes of Proceedings Inst. C.E., vol. xxx. p. 29.
[2] *Ibid.*, vol. xxix. p. 301.
[3] *Ibid.*, vol. lxxxvi. p. 40.

railways abroad to which Mr. Brunlees was Engineer:—The Minas and Rio in Brazil; the Central Uruguay and Hygueritas; the Porto Alegre and New Hamburg; and the Bolivar, which serves the Aroa copper mines in Venezuela.

The work of Sir James Brunlees was not, however, confined to railways. For many years the port of Bristol, at one time second only to that of London, had been suffering severely from want of sufficient dock accommodation. Large vessels, if they happened to arrive during neap tides, had to remain at anchor in the roadstead at the mouth of the Avon, waiting for spring tides to give sufficient depth of water in the approach to the docks, and there was also the risk of navigating the narrow and tortuous course of the River Avon from the Bristol Channel to the city. Although several plans had been submitted from time to time by eminent Engineers, the Town Council had been invariably divided in opinion and consequently no steps had been taken to carry any of them into effect. At length Mr. Brunlees was consulted, and he recommended the construction of a dock at the mouth of the river which should cover an area of about 16 acres. His scheme was accepted and an Act of Parliament obtained. The first sod was cut on the 26th of August, 1868, and on the 24th of February, 1877, the Avonmouth Dock was opened for traffic. An account of the work was presented to the Institution in the following year by the Resident Engineer, Mr. J. B. Mackenzie.[1] A report made by Mr. Brunlees to the Directors of the Bristol Port and Channel Dock Company in 1871, may be found in the library of the Institution. In connection with this work he designed and constructed the Clifton Extension line, which brought the dock into connection with the Great Western and the Midland Railway systems. Mr. Brunlees was also Engineer to the Whitehaven Dock Works, described by Mr. J. Evelyn Williams, the Resident Engineer, in a Paper[2] published at the same time as the account of the Avonmouth Dock. The works were designed and carried out by Mr. Brunlees, and, in addition to a wet dock and railway, included the construction of new piers in the harbour and the carrying out of other important improvements in connection with the port. In the library of the Institution is a report he made to the Town and Harbour Trustees in January, 1870. He also designed and constructed the Lynn Dock in Norfolk which covers about $6\frac{1}{2}$ acres.

In addition to railway and dock work, Sir James Brunlees

[1] Minutes of Proceedings Inst. C.E., vol. lv. p. 3.

[2] *Ibid.*, vol. lv. p. 36.

designed and erected piers at Southport, Llandudno, New Brighton, and Southend; that at Southport being $\frac{3}{4}$ mile long and that at Southend $1\frac{1}{4}$ mile long. Amongst other works constructed from his designs may be mentioned two bridges across the River Ouse and the system of water-supply and drainage in operation at Kelso, his native town. In conjunction with the late Sir John Hawkshaw, he was Engineer to the original Channel Tunnel Company from its incorporation in 1872 until 1886, when it ceased to exist as an independent company. In addition to an extensive Parliamentary practice, he frequently acted as arbitrator in cases in which important railway interests were involved.

Sir James Brunlees died, after a long illness, on the 2nd of June, 1892, at the age of seventy-six years. In disposition he was reserved and quiet, but steady and unswerving in his friendships and ever ready to do a kindly action or to extend a helping hand. By hard work, untiring energy and marked self-reliance he raised himself from a comparatively humble position and achieved distinction and honour as an Engineer of recognized worth and ability. In 1845 he married Elizabeth, daughter of the late Mr. John Kirkman, of Bolton-le-Moors. He was elected a Member of the Institution on the 7th of December, 1852. In addition to the Papers referred to above, he presented in 1862 a communication entitled, "Railway Accidents—Their Causes and Means of Prevention."[1] He was elected a Member of Council in 1865, a Vice-President in 1878, and served the office of President during the session 1882–83, delivering on the 9th of January, 1883, an Address[2] dealing mainly with the most important engineering works recently completed or then in progress.

WILLIAM ELLIOT, eldest son of the late Dr. Elliot, was born at Stratford, Essex, on the 17th of February, 1827, and was educated at the Grammar School of that place and subsequently at King's College, London. In 1842 he was articled to the late Mr. John Seaward, of the Canal Ironworks, Limehouse, and from 1845 to 1848 was a pupil of the late Mr. Joseph Cubitt, Vice-President. During that time Mr. Cubitt was constructing the branch of the South Eastern Railway from Ashford to Canterbury, Ramsgate and Margate, and also the Great Northern Railway, on

[1] Minutes of Proceedings Inst. C.E., vol. xxi. p. 345.
[2] *Ibid.*, vol lxxii. p. 2.

both of which works Mr. Elliot was engaged. After the completion of the latter line, he served on its London District for two years as an Assistant Engineer and for one year as Resident Engineer.

In 1851 Mr. Elliot was engaged for a short time only on the East Indian Railway, the death of his brother rendering it necessary for him to resign this appointment and return to England. After devoting some time to the arrangement of family affairs, he went to Russia for six months for a private firm to make preparations for the establishment of saw-mills, and then in 1854 and 1855 acted as Resident Engineer for his old master, Mr. Cubitt, on the drainage of the London Necropolis Company's estate and on the works for its cemetery at Brookwood, near Woking. In the latter year he was appointed by the Government of Brazil Engineer-in-Chief of the Province of São Paulo, which post he held until 1858. He next acted under the late Mr. W. M. Peniston, as Resident Engineer on the Recife and São Francisco Railway, an account of the construction of which is contained in a Paper on "Public Works in Pernambuco,"[1] presented to the Institution by Mr. Peniston in 1863.

From 1861 to 1864 Mr. Elliot was employed under the late Mr. John Watson on the Bahia and São Francisco Railway, having charge for the last year of that time of the completion and maintenance of the line. He then acted for three years as chief Assistant for Messrs. Smith, Knight and Co. on the construction of about 70 miles of the heaviest portion of the Mexican Railway, after which he returned to England. After being engaged for a short time in deepening the River Blackwater at Maldon, in Essex, by dredging, Mr. Elliot was appointed in 1868, Engineer-in-Chief to the Belgian Public Works Company for the improvement of the City of Brussels, where he carried out extensive drainage works, the diversion and arching of the River Senne, and the erection of the new Exchange and of the Central Markets. An account of these works may be found in *The Engineer* of the 14th of January, 1870. Unfortunately the Company failed in 1871, owing to the insufficient capital with which it had been floated.

On leaving Brussels, Mr. Elliot acted for Messrs. Clark, Punchard and Co. during the construction of tramways at Buenos Ayres, and was then appointed Manager and Engineer-in-Chief to the Monte Video Harbour Improvement Company, formed for the purpose of carrying out a concession from the Government for

[1] Minutes of Proceedings Inst. C.E., vol. xxii. p. 385.

the dredging of the harbour and for additions to the custom-house, as well as of eventually constructing a breakwater and enclosing the harbour in accordance with a plan which had been submitted to the Government by the late Mr. La Trobe Bateman, Past-President Inst. C.E. The dredgers and barges were sent out in pieces and had to be put together in a place where few facilities existed for such work. The foundations of the sea-wall of the custom-house, exposed to very rough weather, were formed of a solid continuous block of concrete in 20 feet of water where no hold was to be had for piles to form a coffer dam, the bottom being of solid gneiss-rock. Owing to political changes the latter part of the programme was not carried out; financial embarrassment arose and Mr. Elliot had no alternative but to send in his resignation.

He again returned to England in 1875 and for the next few years was engaged in examining and reporting on various projects. In 1879 he represented Messrs. Wilson, Sons and Co. on the construction of the Great Western of Brazil Railway in the province of Pernambuco and had charge from the commencement to the completion of the line in 1883. He then went to Buenos Ayres and for the next six years carried out for Messrs. Devoto, the contractors, the construction of the Buenos Ayres drainage works. In January, 1891, he was appointed by Messrs. De Morgan, Snell, and Co. Manager and Engineer of a large cotton-mill at Pernambuco. After selecting a site and completing the necessary negotiations Mr. Elliot was making rapid progress with the erection of this mill, when he was attacked by yellow-fever, from which he died on the 19th of June, 1892.

Mr. Elliot was a man of high principle, strict integrity and firmness of character. He enjoyed the confidence and esteem of his employers and of those who worked under him, and held the highest testimonials from many of the leading South American Engineers. He was elected an Associate of the Institution on the 1st of December, 1863, was placed in the class of Associate Member on its creation in December, 1878, and was transferred to the class of Member on the 28th of March, 1882.

JOHN GEORGE GAMBLE, eldest son of Dr. Harpur Gamble, R.N., was born on the 22nd of January, 1842. After private tuition, he went in 1854 to the Royal Naval School, New Cross, where he remained until 1859, when he obtained a Mathematical

Demyship at Magdalen College, Oxford. He took a First Class in Moderations in 1861 and gained the Junior Mathematical University Scholarship in the following year. He was placed in the Second Class in the Final School of Literæ Humaniores in 1863 and in the First Class in the Mathematical School in 1864. Some years later he obtained the Gold Medal for the Johnson Memorial Prize Essay, the subject being the "Laws of Wind." Mr. Gamble remained at Oxford after taking his degree and, amongst other work, for some time took the Mathematical Lectures at Lincoln College.

In 1866 he became a pupil of Mr. (afterwards Sir) John Hawkshaw and was soon sent to the works of the New Albert Dock at Hull, of which Mr. J. C. Hawkshaw was the Resident Engineer. Mr. Gamble at the end of 1870 was appointed by Mr. Hawkshaw Resident Engineer of the new intercepting and outfall sewers at Brighton, an account of which he presented to the Institution.[1] The tunnelling work followed a sinuous course so as to keep beneath the high road, and in setting it out he adopted with ordinary instruments very perfect arrangements, which depended for their success on well thought-out and systematical methods of eliminating errors by taking true averages of many observations.

Mr. Gamble was an active secretary of Section G of the British Association at Brighton in 1872.

In 1874 Sir John Hawkshaw was requested by the Government of Brazil to advise as to several of the important harbours in that country, and Mr. Gamble, with the late Mr. James Graham, an experienced surveyor, went, with two assistants, Mr. Murray and Mr. Hamilton Dobson, to collect the information Sir John Hawkshaw required. The harbours specially to be reported on were Maranhaõ, Ceará,[2] Recife or Pernambuco, the mouth of the Parahyba River leading to Campos, and Rio Grande do Sul. The staff left England in July, 1874, and went first to Pernambuco. Mr. Graham and the two assistants devoted themselves especially to the land surveys while Mr. Gamble undertook the soundings, borings and the collection of information as to tides and currents and as to the materials to be found. At Ceará Mr. Murray was taken ill of yellow fever and died. Mr. Graham was overcome by the heat and had to return, first to Pernambuco and then to Europe; and while Mr. Gamble and Mr. Hamilton Dobson were on the voyage to Pernambuco Mr. Dobson was taken

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[1] Minutes of Proceedings Inst. C.E., vol. xliii. p. 191.

[2] *Post*, p. 390.

ill and died. Mr. Gamble was thus left alone to complete the work at the two important southern rivers. He was fortunate in obtaining an assistant in Mr. Edward Compton, who had just finished work at Maranhaõ. Mr. Compton speaks in terms of great praise of the energy of Mr. Gamble in carrying out the soundings and other work under circumstances of difficulty and danger, especially at the mouth of the Parahyba do Sul River and when landing at Torres (on the coast between Rio Grande do Sul and Santa Catharina) to examine the stone obtainable in the neighbourhood. Mr. Gamble returned to England in April, 1875, and was engaged for some little time in bringing together the results of his work. Sir John Hawkshaw's report was made in July.

Immediately after this Mr. Gamble was appointed Hydraulic Engineer to the Government of Cape Colony, where he arrived in October, 1875, studying the Dutch language on the voyage. He at once made an extended tour through the northern districts, embodying the information obtained in a series of valuable reports on which useful legal enactments have since been based. At Port Elizabeth, which he next visited, the Municipality carried out works in accordance with his recommendations, the result being that Port Elizabeth possesses the finest waterworks in South Africa. These formed the subject of a Paper read before the Institution in 1883.[1] Under an Act of 1877, consequent on Mr. Gamble's report, a fair amount of progress in irrigation was made. The chief Government works executed under his supervision were a storage-reservoir at Brand Vley, Annshaw Irrigation Channel, and the Stolshoek and Van Wyk's Vley reservoirs; the last in a most exceptional site for securing economy in the construction of the impounding dam and works. Among the various town water-supplies, in addition to that of Port Elizabeth already referred to, carried out under Mr. Gamble's supervision, were those of King William's Town, East London, Queenstown, Somerset East, Riversdale and Graaff Reinet. These and other works in the Colony were described in a Paper [2] presented to the Institution in 1887.

Mr. Gamble induced the Government to establish rain-gauges at every magistracy, thus raising the number of trustworthy recording stations to 250; he produced the first good rainfall maps and procured the publication of daily weather-bulletins, undertaking in his office all the work of collating the reports.

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[1] Minutes of Proceedings Inst. C.E., vol. lxxiv. p. 128.

[2] *Ibid.*, vol. xc. p. 255.

He also took a keen interest in everything relating to scientific and educational matters in the Colony, as in the Philosophical Society, the Public Library, and especially as Examiner and Member of Council of the Cape University. The Parliamentary Papers of the Colony indicate his industry within and without his department. A careful list of all recorded heights in the Colony and a catalogue of the books and papers in all languages relating to climate in South Africa, are examples of his industry in matters outside his duties. In 1878 Mr. Gamble married Miss Constance Brounger, daughter of Mr. W. G. Brounger, Engineer-in-Chief for the Cape Government Railways, and had three daughters. On the abolition of his office in 1886 he returned to England.

Consequent on the Report of a Royal Commission, consisting of the late Sir James Allport, Mr. Abernethy, Mr. J. Wolfe Barry and Mr. J. T. Pim, on Public Works in Ireland, the Government determined in July, 1887, to appoint a "Chief Hydraulic Engineer." Mr. Gamble received the post and at once took up his duties, which consisted in the first place in preparing plans for application to Parliament in regard to the Rivers Barrow, Bann and Shannon. The scheme for the River Barrow required much investigation in working out the details of the system determined on for embanking the higher reaches of the river and dealing by back drains with the low-level ground behind the banks. In the Session of 1888 the three schemes had to be abandoned without coming before a Committee, owing to opposition in the House of Commons; they were again introduced in the Session of 1889, when the project for the River Bann passed the Committee, but for want of time had to be withdrawn.

For the Barrow, a district the condition of which the Royal Commission described as "deplorable," Mr. Gamble, after careful surveys and most painstaking investigation and calculations, matured a scheme in which the combination of moderate excavation in the river-bed with small embankments set back from the edge of the channel was shown to be the most economical method of protecting the land from floods. Any difficulties from the back drains were such as could be met without inconvenience. The estimate was £360,000. As soon as the project had been got ready for application to Parliament, full surveys and designs for the works were proceeded with during the year 1888 and were completed in 1889.

The drainage of the River Shannon was a subject which had been very much studied, and portions of the recommendations made by Mr. Bateman in 1867 had been carried out. The Royal

Commission recommended the prosecution of Mr. Bateman's works. The Government proposed to leave the construction in the hands of the Board of Works, but Mr. Gamble, in his capacity of Chief Hydraulic Engineer, advised with regard to the designs to be submitted to Parliament. The Bills of 1888 and 1889 for the Shannon works were not proceeded with, but some important recommendations of the Royal Commission have since been carried out. Mr. Gamble, in evidence before the Shannon Fisheries Inquiry, 1889, explained fully his views as to the works which should be undertaken throughout this river.

Notwithstanding these delays, inseparable perhaps from undertakings requiring Parliamentary sanction, the post thus occupied by Mr. Gamble seemed to promise a long career of usefulness in the public service. Unhappily these hopes were destined to be summarily disappointed. In the autumn of 1889 he was attacked by typhoid fever, which, after an illness of forty-eight days, proved fatal on the 7th of November, although, almost to the last, a favourable issue had been looked for.

Combining in a rare degree of excellence great mental gifts, diligently trained in the pursuit of truth, with a singular sweetness and modesty of character, Mr. Gamble, at every stage of his career, secured the esteem of those with whom he worked. His death called forth many sincere expressions of sorrow when it became known in South Africa; at home, a memorial from his Irish staff took the appropriate form of a contribution to the capital of the Benevolent Fund of the Institution.

Mr. Gamble was elected an Associate of the Institution on the 7th of December, 1869, and was transferred to the class of Member on the 28th of November, 1876. For the Papers above referred to he was awarded a Telford Medal and three Telford Premiums.

The following is a list, chronologically arranged, of the various Reports and Papers by Mr. Gamble:—

"The Brighton Intercepting and Outfall Sewers."—Report of the British Association for the Advancement of Science, Brighton, 1872, p. 245.

"Report on the Water Supply of Cape Town."—Cape Town, 1875.

"The Brighton Intercepting and Outfall Sewers."—Minutes of Proceedings Inst. C.E., vol. xliii. p. 191.

"Reports of the Hydraulic Engineer" (1876-85).—Parliamentary Papers, Cape of Good Hope.

"Report on the Water Supply of Port Elizabeth."—Port Elizabeth, 1877.

"Rainfall of South Africa," 26th June, 1878.—Transactions South African Philosophical Society, vol. i. p. 13.

"A Storage-reservoir in the Achterveld," 29th October, 1879.—Transactions South African Philosophical Society, vol. i. p. 219.

"Some of the Problems awaiting Scientific Research in South Africa."—Transactions South African Philosophical Society, vol. ii. p. 91.

"Summer and Winter Temperature in South Africa," 30th March, 1881.—Transactions South African Philosophical Society, vol. ii. p. 104.

"Rainfall in South Africa."—Quarterly Journal of the Meteorological Society, vol. vii. 1881, p. 3.

"Note on a Comparison of Maximum and Minimum Temperature and Rainfall observed on Table Mountain and at the Royal Observatory, Cape Town, during January and February, 1881."—Quarterly Journal of the Meteorological Society, vol. vii. p. 249.

"Proposals of the Table Mountain Water Supply Company," 26th April, 1882.—Transactions South African Philosophical Society, vol. iii. p. 5.

"The Barometer and the Winds," Annual Address as President of the South African Philosophical Society, 26th July, 1882.—Transactions South African Philosophical Society, vol. iii. p. xix.

"The Waterworks of Port Elizabeth, South Africa."—Minutes of Proceedings Inst. C.E., vol. lxxiv. p. 128.

Annual Address as President of the South African Philosophical Society, 25th July, 1883.—Transactions South African Philosophical Society, vol. iii. p. xlvii.

"Meteorological Notes," 4th December, 1884.—Transactions South African Philosophical Society, vol. iv. p. 10.

"Catalogue of Printed Books and Papers relating to South Africa.—Part II., "Climate and Meteorology."—Cape Town, 1885.

"Altitudes above Sea-level of Places in South Africa South of 20° S. Latitude."—Cape Town, 1886.

"Water Supply in the Cape Colony."—Minutes of Proceedings Inst. C.E., vol. xc. p. 255.

"Rainfall on and around Table Mountain, Cape Town, Cape Colony."—Quarterly Journal of the Royal Meteorological Society, vol. xiv. 1888, p. 12.

The whole of these documents may be found in the Library of the Institution.

JOSEPH HINDLE, third son of the late Rev. Joseph Hindle, B.D., Vicar of Higham near Rochester, was born at Gravesend on the 5th of April, 1838, and was educated first at a preparatory school at Ramsgate and then at Oakham Grammar School under the Rev. W. S. Wood, D.D., the present vicar of Higham. In March, 1856, he was articled for three years to Messrs. George Rennie and Sons and in June, 1859, became a pupil of Mr. W. M. Brydone, then Chief Engineer of the Great Northern Railway, by whom he was subsequently employed on the Garston and Liverpool Railway.

In the autumn of 1861 Mr. Hindle obtained an appointment as an Engineer in the service of the Peruvian Government. For six years, during which time he passed from the Third to the First Class, he was chiefly occupied in making surveys, plans and estimates, and in preparing reports, and carried out little actual constructive work, with the exception of the conversion of the corvette "Loa" into an ironclad and her subsequent recovery after she had been run aground in the harbour of Callas. In 1866 he was granted permission to practise privately, his services, however, still being retained by the Government. In February of the same year he was appointed a Resident Engineer on the Lima Railways under the late Mr. Oswald Younghusband. In 1868 and 1869 he made preliminary surveys for the Pacasmayo Cajamarca Railway across the Andes, about 100 miles in length, and for the line from Chimbote to Huaraz and Recuay, cutting through the Cordillera Negra, a range about 16,000 feet high. The length of the latter survey was about 130 miles of most difficult country, the height of Recuay above the sea being over 11,000 feet. He also made the final survey of the first section (40 miles) of the Oroya Railway, on the construction of which he subsequently acted as District Engineer. In August, 1871, he was appointed Engineer-in-Chief of the Eten, Chiclayo and Ferenafe Railway, a line of about 30 miles. The principal works were three bridges over rivers subject to heavy floods, and a screw-pile pier at Eten, 2,600 feet long, through a heavy surf. In December of the following year he was placed by the Government in charge, as Engineer and Manager, of the Ylo and Moquegua Railway, 67 miles in length. The line was sold to a private company in 1877, when Mr. Hindle retired from the Government service and left Peru for England in order that his children might be educated in this country.

From that time Mr. Hindle seems to have carried out very little professional work until October, 1890, when he was sent by Messrs. James Livesey and Son to Yucatan, Mexico, to examine and report upon the existing railways of that empire and also to make an investigation and to prepare estimates for the construction of additional lines, to gather statistics as to probable traffic, and, in fact, to obtain such information as would enable that firm to report as to the advisability of purchasing the lines already in existence and of executing new works. He returned in the following April, having fulfilled this mission in a most complete and satisfactory manner, and was then employed by Messrs. Grace Brothers & Co., contractors, on the Central Railway of Peru. Ill

health, however, compelled him to return to England in the autumn of 1891, and he died in London on the 18th of August, 1892, at the comparatively early age of fifty-four.

As an Engineer, Mr. Hindle was able and enthusiastic, and might always be depended upon to carry out thoroughly and satisfactorily whatever work was entrusted to him. As a man he was genial and kind-hearted, and deservedly popular among all who came into contact with him. He was elected a Member of the Institution on the 2nd of December, 1879.

ALEXANDER CARNEGIE KIRK, LL.D., who died suddenly at Glasgow on the 5th of October, 1892, was senior partner in the firm of Messrs. Robert Napier and Sons, the engineers and shipbuilders of Govan. He was born on the 16th of July, 1830, at Barry, Forfarshire, of which parish his father was minister, and was educated at the Burgh School, Arbroath, and at the University of Edinburgh. He then went to Glasgow, where he served an apprenticeship of five years to the late Mr. Robert Napier at the Vulcan Foundry, Washington Street.

On the completion of his apprenticeship in 1854 he proceeded to London and eventually became Chief Draughtsman in the office of Messrs. Maudslay, Sons and Field, with whom he remained six years. He then accepted the post of Engineer and Manager of the paraffin oil works of Messrs. Young, Meldrum and Binney at Bathgate, for which firm he constructed the first practical atmospheric refrigerating-machine and subsequently designed and erected new works at West Calder, involving the sinking of shale pits and the construction of a branch line from the North British Railway. At both these works he displayed great genius for devising means of facilitating labour and economizing energy; numerous improvements in shale-breaking and cooling-machinery were introduced by him, one of his inventions being a freezing-machine for use in separating the solid paraffin in the oil. Hitherto this had been done by ether-machines, but ether being dangerous Dr. Kirk in 1862 commenced a series of experiments on air-machines, with the result that he designed and made the dry-air freezing-machine which is now in a modified form so extensively used in connection with the carriage and storage of meat from the colonies. In 1864, he read before the Institution of Engineers in Scotland a Paper[1] on this subject and nine years later

[1] Trans. Inst. Engs. Scotland, vol. viii. p. 14.

he submitted to this Institution a similar Paper,[1] for which he was awarded a Watt Medal and a Telford Premium.

In 1866 Dr. Kirk returned to Glasgow as Manager of Messrs. James Aitken and Co.'s works at Cranston Hill, where he remained for two years, constructing marine and other engines, and oil-plant, both for this country and Australia. He then practised as a Consulting Engineer from 1868 to 1870, during which time the moist-air refrigerating-machine was produced. Soon after the death of Mr. John Elder in the latter year Dr. Kirk was appointed Manager of the Centre Street and Fairfield Engine Works, where he found ample scope for his great ability and soon became regarded as one of the leading Marine Engineers in the kingdom. Under his supervision the compound-engines made by Messrs. John Elder and Co. were greatly improved, and from his special designs the three-cylinder compound-engine was introduced. He also at a later date carried into effect the idea of a triple-expansion type of engine, the first attempt it is believed to apply the principle of triple-expansion to the engines of a steamship. In 1874 he designed and fitted on board the screw-steamer "Propontis," belonging to Messrs. W. H. Dixon and Co. of Liverpool, engines[2] on this principle, to work at a pressure of 150 lbs. per square-inch, having water-tube boilers; but owing to the failure of these boilers, and it being impossible at that time to work ordinary boilers at such a pressure, the engines had to be re-converted to the compound principle, with ordinary boilers. Thus the greatest modern improvement in marine engineering was checked for nearly eight years. The design of the engines of the "Propontis," having three cylinders and three cranks, is the one now in almost universal use for triple-expansion marine-engines.

In 1877, the year after the death of Mr. Robert Napier, Dr. Kirk severed his connection with the Fairfield establishment and, with Messrs. John and James Hamilton, acquired the business of Robert Napier and Sons. Four years later, after steel had been introduced, and it became practicable to obtain higher pressures in an ordinary form of boiler, Dr. Kirk again turned his attention to the triple-expansion engine, and having induced Messrs. Geo. Thompson and Co., of the Aberdeen clipper line of sailing-vessels, to try this type of engine, he built and fitted a set for the screw-steamer "Aberdeen" which proved beyond doubt that there was a considerable saving to be obtained over the

[1] Minutes of Proceedings Inst. C.E., vol. xxxvii. p. 244.

[2] *The Engineer*, 1 May and 14 August, 1874.

compound type. A Paper "On the Triple-Expansion Engines of the steamship "Aberdeen," was presented by Dr. Kirk to the Institution of Naval Architects in 1882.[1] In less than four years all the Marine Engineers in this country acknowledged the revolution which had taken place. The compound-engine became obsolete and the triple-expansion engine took its place, effecting a reduction of quite 25 per cent. in the consumption of coal and giving great impetus to shipbuilding and marine engineering. This type of engine has since been adopted not only by the English Admiralty but by most foreign governments.

Dr. Kirk received from the University of Glasgow the honorary degree of LL.D. He was a Fellow of the Royal Society of Edinburgh; a Vice-President of the Institution of Naval Architects; Past-President of the Institution of Engineers and Shipbuilders in Scotland; and a Member of the Institution of Mechanical Engineers. In all these societies he took considerable interest and among the Papers he contributed to their Transactions the following, in addition to those already referred to, may be specially mentioned:—"On the Effect of Punching on Iron and Steel Plates";[2] "On a Method of Analysing the forms of Ships and determining the mean angle of entrance";[3] and "On Cracks and Annealing of Steel."[4] He was elected an Associate of this Institution on the 7th of February, 1865, and on the 26th of February, 1878, was transferred to the class of Member. Reference has already been made to his Paper on the "Mechanical Production of Cold," read in 1874. Ten years later he delivered at the Institution by the invitation of the Council a lecture on "Compressed-Air and other Refrigerating Machinery," which formed one of the series of lectures on "Heat in its Mechanical Applications."

All who had the privilege of knowing Dr. Kirk will feel that a gap has been caused by his death not easy to fill. He was true and generous to a fault, always anxious and ready to listen to and discuss any proposed improvement in engineering, and his gentleness and kindness of heart endeared him to all his associates. As a designer of marine-engines, Dr. Kirk exhibited great talent and originality; no detail was too small to be neglected and no experiment too unimportant to be carefully conducted. Indeed his

[1] Trans. Inst. Naval Architects, vol. xxiii. p. 33.
[2] *Ibid.*, vol. xviii. p. 303.
[3] *Ibid.*, vol. xxi. p. 96.
[4] *Ibid.*, vol. xxiii. p. 130.

success must be attributed to that combination of ability and industry which is so rarely found in the present day. Not only on the Clyde but in every port to which ships and engines find their way, the name of Dr. Kirk has for many years been respected as that of one of the cleverest, shrewdest and most honourable of Marine Engineers.

ALEXANDER THEODORE LAVALLEY was born in November, 1821, and was educated at Tours and at the École Polytechnique, Paris, from which he passed out as a sub-lieutenant of military engineers. He soon however resigned his commission, and proceeding to England entered in 1843 the works of Messrs. Bury, Curtis and Kennedy, engineers, of Liverpool, passing through the shops and drawing-office, in order to gain a thorough knowledge of mechanical construction and detail. Having spent two years in this way, he returned to France and passed twelve months in the drawing-office of the Chemin de Fer du Nord, under the direction of Mr. Clapeyron, engaged in the design of locomotives and of railway plant generally.

Mr. Lavalley was now to reap the benefit of the practical experience he had thus gained. In 1846, when only five-and-twenty years of age, he was appointed to the important post of Engineer and Manager of the well-known works of Messrs. Ernest Gouin and Co., at Paris, where he remained until 1863. During that time he was engaged in the design and construction of locomotives, iron bridges and machinery of every description, much of the work being for Russia, where also he made the only tunnel on the long line from St. Petersburg to Warsaw. Last, but not least, he undertook, on the failure of the native contractors, the completion of the line across the Pyrenees on the Northern Railway of Spain. Under his direction the establishment of Messrs. Gouin at Batignolles not only maintained its previous standing, but increased from year to year in importance and in reputation.

From 1864 to 1870 Mr. Lavalley was engaged, in conjunction with the late Mr. Paul Borel, in carrying out the contract for the dredging of the Suez Canal. Up to that time the work of dredging had been performed entirely by manual labour and the first task of Mr. Lavalley and Mr. Borel was to effect a complete revolution by the introduction of mechanical plant and appliances. Mr. Lavalley presented to the Société des Ingénieurs Civils of

Paris three Papers[1] which give a very complete account of the works thus carried out by him and his associate. Great difficulty was experienced in obtaining European labourers to take the place of the native fellahs; additional dwellings had to be provided for their accommodation, and the accessory canals had to be widened for the conveyance of the large dredging-machines. In the course of the discussion upon a Paper by Mr. Harrison Hayter on the "Amsterdam Ship Canal," Mr. Lavalley gave a short but interesting account[2] of the method he employed in delivering the dredgers on the Suez Canal and in bringing up the soil, which was very variable. He had found, however, that long shoots were available for all kinds of soil. In dealing with mud, the shoots, 230 feet long, carried away the soil with hardly any inclination; but to get rid of the sand mixed with shells—which formed a coating and protected the sand from the action of the water—he had used a pair of endless chains working down the shoot. The dredgers could turn out about 2,000 cubic-yards of thick clay in fifteen hours. All difficulties were rapidly overcome and the work was successfully accomplished. About eighty million cubic-yards of material were excavated and at one time nearly 30,000 labourers were employed on the works. After the opening of the canal for traffic on the 17th of November, 1869, Mr. Lavalley was appointed by the company Chief Engineer for the completion and maintenance of the works, which position he held until 1874.

In 1875 and 1876 Mr. Lavalley made for the French Channel Tunnel Company, of which he was a prominent member, some geological researches and soundings near and across the Straits of Dover, in continuation of those made by the late Sir John Hawkshaw. He presented several reports which may be consulted in the library of the Institution. He was also for some time Engineer and Director of the Compagnie du Port et du Chemin-de-fer de la Réunion, for which he constructed a harbour and railway in the island of Réunion.[3] The latter years of his life were devoted more to politics than to engineering. He was a Deputy from 1875 to 1885, when he was elected Senator for the Department of Calvados, in which he possessed landed property. He also interested himself in agricultural and industrial questions.

Mr. Lavalley died at Bois-Thillard, near Pont l'Evèque in

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[1] Comptes rendus de la Société des Ingénieurs civils, 1866, 1867 and 1869. See also "Suez Canal Tracts" (3 vols.), in Library of the Inst. C.E.

[2] Minutes of Proceedings Inst. C.E., vol. lxii. p. 46.

[3] Comptes rendus de la Société des Ingénieurs civils, 1884 and 1886.

Normandy, on the 20th of July, 1892, from the effects of an operation for cataract, from which he had for some time suffered. He was a man of high character, and possessed those qualities of prescience and enterprise which combine to make the successful captain of industry. His courage and readiness to incur great responsibility were well exemplified by the Suez Canal contract; but for his willingness to undertake, at the risk of reputation and fortune, the arduous task of completing a navigable waterway within a given period, the works would, in all probability, have been summarily stopped, or would have languished until ridicule and want of means forced the ruined promoters to desist. His courtesy and geniality disarmed hostility and made him universally popular. Mr. Lavalley was well known to many Englishmen, by whom he was valued as a warm friend and a reliable man of business. He was an officer of the Legion of Honour and a Member of the Société des Ingénieurs civils, of which he served the office of President during the year 1877. He was elected a Member of the Institution on the 4th of March, 1879.

A fuller account of Mr. Lavalley's works will be found in the Comptes rendus de la Société des Ingénieurs civils for 1892.

PERCEVAL MOSES PARSONS was an engineer well known for his mechanical skill and experience, for his inventive ability and for some happy practical discoveries in metallurgy.

His father was Mr. John Parsons, of Scraptoft House, Leicestershire; he was born in London in 1819 and was educated at a private school near Blackheath, in which neighbourhood he from old associations afterwards resided from his marriage until his death. Having shown an early aptitude for mechanical pursuits, he was placed when only fifteen years old under the Chief Engineer of Portsmouth Dockyard; and this experiment proving satisfactory he was regularly articled in 1836 to the well-known engineering firm of Braithwaite, Milner and Co., where he remained until he was of age. It was thought desirable that he should see something of railway works, at that time becoming so popular and extensive, and in 1841 he enlisted as assistant to Mr. P. S. Bruff, the Engineer of the Eastern Counties Railway. Here he remained till 1845, actively engaged in laying out and superintending the construction of works and in the other duties of a Resident Engineer. In 1846 he returned for a short time to mechanical work as Assistant Engineer to Messrs. J. and G. Rennie at Black-

friars, after which he put his mechanical knowledge to good practical use by undertaking the important post of Superintendent of the large fixed plant and machinery on the Eastern Union Railway.

In 1850 Mr. Parsons went into business on his own account and was soon successfully engaged on various engineering works chiefly connected with railways and their appliances, too numerous to specify. It must suffice to mention some few of his most interesting occupations. His attention had become specially directed to the design and construction of railway fittings; he saw their defects and his ingenious and inventive mind soon led him to devise ameliorations and improvements. His earliest efforts in this way were to take out patents[1] for improved switches and axle-boxes, which he worked at first in his own office with the aid of friends. But afterwards there was formed a small association of engineers, called the "Permanent Way Company," with the special object of working patents for railway appliances and apparatus. This Company became well-known and supported among railway interests and Mr. Parsons connected himself with it, several other patents for railway appliances being afterwards taken out by him.

In 1853 he designed a great scheme for the railway accommodation of the Metropolis. To understand the merits of this scheme it must be recollected that at that time there were no Metropolitan, nor District, nor North London local lines, no stations at Charing Cross or Cannon Street, nor was the Thames Embankment in existence; the termini of the various lines running into London were wide apart from each other and no railway communication whatever existed between the two banks of the River. Mr. Parsons' proposal was sufficiently indicated by the title of a pamphlet he published, which ran as follows :—

PROPOSED LONDON RAILWAY[2]

to afford direct Railway Communication between the City and Westminster, and all the Western Suburbs, including Pimlico, Chelsea, Knightsbridge, Brompton, Kensington, Hammersmith, Bayswater, Notting Hill, Shepherd's Bush, Turnham Green, Chiswick, Brentford, Kew, &c., &c.; and to unite the whole of the existing Metropolitan Railways, both North and South of the Thames, and provide them with a general Central Station.

This central station was the great feature; it was proposed to

[1] Commissioners of Patents—Abridgments of Specifications—Carriages, &c., for Railways, 1807–66, pp. 246, 393, and 472.

[2] *Vide* Library Inst. C.E.

be laid out on a very ample scale on the north bank of the Thames near Charing Cross, behind Northumberland House. From this station lines were to diverge—1. Westward and north-westward, through Pimlico, Brompton and Kensington, joining the Great Western and North Western Railways. 2. South-westward, crossing the river to the South Western Line. 3. Eastward, for some distance along the north coast of the river and then passing through the City to the Great Eastern and Great Northern Railways; and 4. South-eastward, crossing the river to the South Eastern and Brighton Lines. The portions through populous districts were to be partly tunnelled and partly elevated, according to circumstances, and the whole was estimated to cost three millions sterling. Mr. Parsons wisely endeavoured to interest engineers of high standing in the scheme and succeeded in inducing Mr. Robert Stephenson to give his support as Consulting Engineer and Mr. (afterwards Sir John) Hawkshaw as joint acting Engineer with himself. At one time the scheme appeared promising, but the Crimean War stopped any immediate proceedings and when this was over other proposals, of less wide pretensions, were put forward, and various circumstances interfered with the further prosecution of the scheme, which indeed was probably in advance of the time. But it may be questioned whether, if some such comprehensive measure had been adopted, the Metropolis might not have been saved much of the difficulty since experienced in its railway communications.

Mr. Parsons was, unfortunately, a sufferer from the almost universal delusion of clever inventors, namely, the idea that if they can do anything which is of great public benefit, the authorities will patronize and reward them. One of the most common forms of this hallucination refers to improvements in implements of warfare and Mr. Parsons was stricken with this form of the mania. It was about the period when rifled cannon were fast superseding the old smooth bores and it occurred to him that he might save the country great loss if he could find means of changing the old form into the new. In 1855 therefore he took out a patent[1] for converting the old cast-iron artillery into rifled guns, by boring them out and inserting a steel tube. The work in connection with this invention and his attempt to obtain its adoption by Government occupied some eight or ten of the best years of his life and ran away with an enormous sum of

[1] Commissioners of Patents—Abridgment of Specifications—Fire-arms, &c., 1588–1866, p. 207.

money. The affair was complicated by a claim of Major, afterwards Sir William Palliser for a similar invention, and Mr. Parsons was left unrecognized. At a later period, after great endeavour, he succeeded in getting an official inquiry, and the matter was referred to Mr. (now Sir) Charles Hutton Gregory. Judgment was given in Mr. Parsons' favour, and he was awarded the very inadequate compensation of £1000. Full particulars of this invention and the proceedings consequent thereon will be found in the engineering journals of the period. A pamphlet he wrote in 1863 on "Guns *versus* Armour Plates" may be found in the library of the Institution.

In February, 1867, he patented an improvement in bolts; the experiments of the Armour Committee had brought to light the apparent paradox that by reducing the quantity of metal in certain parts of bolts they were made better able to resist shocks without fracture, and Mr. Parsons utilized this principle in several ingenious ways. Some experiments in 1868 at Shoeburyness on the 'Millwall shield,' fitted with these bolts, proved their advantages.

In 1871 he accepted the appointment of Engineer to the Bessemer Steel and Ordnance Company and superintended the erection of the whole of the Company's new works at East Greenwich, an occupation which lasted for two years.

The question of the guns appears to have turned Mr. Parsons' attention to the study of the use of metals generally, and his experience with machinery had shown him the importance of the arrangements for shaft-bearings and other rubbing-surfaces, for which ordinarily "gun-metal" (an alloy of copper and tin) had been used. He thought he could improve on this and, having established a private mechanical laboratory at his house at Blackheath, he tried a great number of experiments with different metals, and ultimately produced a better compound of copper, tin, zinc and lead, called "white brass," which is now largely used, especially for marine engines.

His success led him to search for another metallurgical desideratum, namely, a material which, while it approached steel in strength, should be free from the liability to corrosion inseparable from all preparations of iron. After some years' experimenting he produced what is called "manganese bronze," prepared by combining ferro-manganese with bronze and brass alloys, in different ways according to the purposes required. There was at first some difficulty in getting it known and introduced, but it was at length taken up by a company, the commercial result of which

has testified sufficiently to the useful character of the invention. It is in large use for the propellers of steamers and in other cases where strength and durability are required in combination. As evidence of the fertility of Mr. Parsons' inventive power, it may be mentioned that between 1851 and 1889 he took out no less than 52 patents, of which 19 had to do with artillery and warlike appliances, 11 with railway apparatus, 11 with metallurgy, and the remainder with miscellaneous subjects.

Mr. Parsons died very suddenly, from an attack of apoplexy, on the 5th of November, 1892. He had married in 1851 a daughter of Mr. Rexford, of Greenwich, who survives him with eleven children.

He was elected a Member of the Institution on the 2nd of December, 1873.

RICHARD JAMES HARRIS SAUNDERS, eldest son of Mr. Richard Taylor Saunders, of Plympton, Devon, was born on the 7th of January, 1835, in the village of Boltberry, near Kingsbridge. In 1856 he was articled for three years to the late Mr. A. F. Livesey, Engineer and Architect, of Portsmouth, with whom he subsequently remained for a time as a partner. In 1860 Mr. Saunders commenced to practise on his own account, taking offices at Ventnor and subsequently in London. In 1862 and 1863 he was engaged on Parliamentary work for Mr. Abernethy, Past President Inst. C.E., in connection with Ventnor Harbour, the construction of which he partially carried out in conjunction with the late Mr. J. H. Tolmé, and was subsequently occupied in the promotion of several Bills for tramway, railway and harbour works in the island.

In 1865 and 1866 Mr. Saunders acted as Resident Engineer on the Waterloo and Whitehall Railway under Sir Charles Fox and Mr. T. W. Rammell. It was proposed to carry the line from a terminus at Scotland Yard in brickwork under the Thames Embankment to the river, through and across which it was to be continued in watertight iron-tubing, encased in cement and laid and fixed in a channel to be dredged out of the bed of the river; on reaching the southern shore, the line was to be carried in brickwork under College Street and Vine Street to a terminus on the north side of Waterloo Station. The works were commenced in the autumn of 1865, but were eventually abandoned. In 1866 and again in the two following years Mr. Saunders promoted,

with Sir Charles Fox, the Newport Junction Line of the Isle of Wight Railway; the Act was obtained in 1868 and the works were carried out under their joint superintendence, the line being completed and opened throughout in 1879. Meanwhile in 1873 and 1874 he promoted and obtained Acts for Fareham Railway and Brading Harbour Improvement and Railway. In connection with the latter undertaking he carried out between 1877 and 1880 the reclamation of 700 acres of mud and the construction of quays at St. Helen's and of the railway from Brading to Bembridge. In 1875 he had taken into partnership his brother, Mr. Theodore R. Saunders, to whom in 1882 he sold the business outright, thus severing his connection of twenty-two years' standing with the Isle of Wight.

For the next four or five years Mr. Saunders' engagements were more or less of a desultory nature. In 1881 and 1882 he prepared schemes for the drainage of Broadstairs and St. Peters and for the extension and improvement of the drainage of Herne Bay, part of which he subsequently carried out. Such work, however, was far from profitable, and Mr. Saunders was only too glad to accept the appointment of Resident Engineer on the harbour works at Ceará in Brazil, offered to him at the close of 1886 by the Ceará Harbour Corporation of London.

The Port of Ceará was one, amongst others, on the coast of Brazil reported upon in 1875 by the late Sir John Hawkshaw for the Brazilian Government.[1] A concession having been subsequently obtained for the construction of a harbour, the prosecution of the work came into the hands of the above Corporation. Mr. Saunders went to Brazil in January, 1887, and during his connection with the undertaking which lasted until September, 1890, he carried out a portion of the works, including an open viaduct on cast-iron piles, a masonry pier and concrete breakwater to enable vessels to be berthed for the purpose of discharging cargo, and the erection of a new Custom House. During that time he constructed some waterworks for the Government of Brazil and subsequently became one of the Engineers on the staff of the Baturité Railway, a State line from Ceará to the interior. While thus engaged he was invited by the Chief Engineering Inspector of the northern harbours of Brazil to proceed to the Province of Maranhão, where there was a prospect of his obtaining an appointment on some large harbour works about to be constructed. On the night of the 27th of June, 1892, the

[1] *Ante*, p. 374.

small coasting-steamer "Alcantara," in which he was a passenger, struck on a reef about 14 miles to the north-west of Fortaleza. Mr. Saunders, who was a good swimmer, threw himself into the sea in the hope of reaching the shore which was not far distant, but was carried out by a strong current and drowned.

Of fine presence and physique and open-handed to a degree which undoubtedly injured his own interests, Mr. Saunders was universally popular. Of a temperament at once sanguine and determined, he seemed to inspire those who worked under him with the same qualities. He was a hard and quick worker, both in the office and in the field, and it is to be regretted that to an uphill fight through life was added an untimely death. Mr. Saunders was elected an Associate of the Institution on the 25th of May, 1880, and was transferred to the class of Member on the 4th of March, 1884.

WILLIAM POWELL SHINN[1] was born on the 4th of May, 1834, in Burlington, New Jersey. After receiving such elementary education as the schools of the town afforded, he went to Pittsburgh early in 1850 and found employment as rodman in an engineer corps, under the charge of Mr. Solomon W. Roberts, then engaged in the location of the Ohio and Pennsylvania Railroad. From August, 1851, to February, 1852, he was Assistant Engineer in charge of a sub-division at Columbia, Ohio, and from April 1852 he had charge of the fuel and water supply of the line. In April, 1853, he was appointed principal Assistant Engineer of the Fort Wayne and Chicago Railroad, in charge of location and construction, in which capacity he continued until October, 1854. In February, 1855, he took charge, as auditor, of the freight accounts of the Ohio and Pennsylvania Railroad, retaining this position until the following November. From March to September, 1856, he was engaged as engineer in the preparation of the land maps and title records of the Ohio and Indiana Railroad, now forming a portion of the Western Division of the Pittsburgh, Fort Wayne and Chicago Railroad. In October of the same year he took charge of the freight accounts of the Pittsburgh, Fort Wayne and Chicago Railroad, and, in addition to these duties, assumed control of the passenger accounts of that Company from February to September, 1857, when he was made general book-keeper, which

[1] This Notice has been abridged from a Memoir which appeared in the Transactions of the American Society of Civil Engineers, 1892.

post he held until September, 1861. At the latter date he was appointed General Passenger Agent; in September, 1863, he was made Superintendent of the Eastern Division, and from October, 1865, to April, 1871, held the office of General Freight Agent.

Upon the organization of the Pennsylvania Company, in April, 1871, Mr. Shinn was appointed General Agent, being entrusted with various important and sometimes confidential commissions for the purpose of investigating the financial affairs and examining the physical conditions of some of the lines, which, by purchase, lease or traffic contracts, became from time to time part of the Western System of Railways under the ownership and control of the Pennsylvania Company. He was also commissioned in 1870 by the Pennsylvania Railroad Company to investigate and report upon the condition of the United Railroads of New Jersey, including the branches and canal and river navigation property, with lines of ferries and transfer vessels. This report determined the lease of these vast properties to the Pennsylvania Railroad Company and led to the adoption of a number of important improvements and extensive changes.

In addition to his other duties, Mr. Shinn undertook in 1871 the construction of the Ashtabula, Youngstown and Pittsburgh Railroad, of which he was President in 1874 and 1875. He also served as Treasurer of the Granite Improvement Company, under the auspices of which this line was built. In January, 1873, he became managing partner of Carnegie, McCandless and Company and took charge of the construction and management of the Edgar Thomson Steel Works at Braddock, Pa. In May, 1874, Mr. Shinn was elected Assistant President and Comptroller of the Allegheny Valley Railroad Company; in the following April he was elected Vice-President; and in April, 1876, a member of the Board of Directors. In the following year, he resigned his office, but remained a member of the Board until March, 1880. At the time of his election as Vice-President he was specially charged with the reorganization of the Company, which had been involved in debt and other complications; and by his skilful management and earnest application he left its financial affairs in a greatly improved condition.

In October, 1879, Mr. Shinn retired from the management of the Edgar Thomson Steel Works and reorganized the Vulcan Steel Company of St. Louis; he rebuilt and started the works and continued in charge until 1881, when he was made Vice-President of the New York Steam Company for supplying steam-heat to the dwellings and industrial establishments of the City.

This office he held until 1887. From 1886 to 1891 he served as Vice-President and General Manager of the New York and New England Railway Company and in 1890–91 he was also President of the Norwich and New York Transportation Company. Among the local industries of his Pittsburgh home he was interested in the Mansfield Coal and Coke Company, of which he was one of the original organizers and for several years President. During the last year of his life he organized the United States Glass Company, a consolidation of sixteen glass manufactories, having a capital of $4,000,000. He was a Director of this Company at the time of his death.

Mr. Shinn was elected a member of the American Society of Civil Engineers in September, 1869; he took an active part in its affairs, and made his beneficial influence felt and appreciated in many ways. On the 15th of January, 1890, he was elected President. His contributions to the Transactions of the Society are numerous and valuable. Among them is a Paper on "Railroad Accounts and Returns,"[1] a subject to which he had given much attention. He advocated the establishment of a uniform system of accounts under the direction of the Railway Commissioners of the States, the plans for which were to be formulated by a Committee of the American Society of Civil Engineers acting in conjunction with the State Commissioners. The discussion took a wide range; and although the recommendations of the Author failed, the ventilation of the question was the means of at least a partial adoption of the suggestions of the Railway Companies by the State Commissioners and by the Inter-State Commission. Mr. Shinn's preliminary report,[2] as Chairman of a Committee on Resistance of Railway Trains, appointed by the Society in April, 1876, contains a description of the newly invented dynagraph and its application for measuring and recording the resistance due to the movements of trains, and furnishes tabulated statements and graphical diagrams of experiments made with that instrument. As a sequel to this report, Mr. Shinn read, at a meeting of the Society in December, 1882, a Paper on the "Increased Efficiency of Railways for the Transportation of Freight,"[3] for which he was awarded the Norman medal. Again, at the Annual Convention in Minneapolis in June, 1883, he read another Paper entitled "How can Railways be made more Efficient in the Trans-

[1] Trans. Am. Soc. C.E., vol. v. p. 215.
[2] *Ibid.*, vol. v. p. 341.
[3] *Ibid.*, vol. xi. p. 365.

portation of Freight?"[1] and later on he again presented to the Society a Paper on "Power Brakes for Freight Trains."[2]

Mr. Shinn was elected in 1875 a member of the American Institute of Mining Engineers, of which in 1876 and 1877 he was one of the Vice-Presidents and in 1880 President. His contributions to the Transactions of the Institute comprise the following original Papers: "Pittsburgh, its Resources and Surroundings;"[3] "The Advance in Mining and Metallurgical Art, Science and Industry since 1875;"[4] "The Distribution of Steam in Cities;"[5] and "The Genesis of the Edgar Thomson Blast Furnaces."[6] In 1890 the American Institute of Mining Engineers and the societies and trades co-operating with it in the reception of the Iron and Steel Institute of Great Britain (of which he was a member) and other guests, requested Mr. Shinn to act as Chairman of the Sub-Committee on Transportation. His natural administrative ability and great practical experience in conducting transportation largely contributed to the success which attended the excursions of more than 500 guests over several thousand miles of railroads, lasting a month and terminating, without delay or accident, promptly at the time fixed.

Mr. Shinn was married in July, 1856, to Miss Sallie Templeton Farley, daughter of Mr. Thomas Farley, of Allegheny, Pa., who died in 1890. Mr. Shinn survived his wife until the 5th of May, 1892, when he died at Pittsburgh, after a somewhat protracted illness. His personal habits were quiet, reserved and unobtrusive, and his mode of life was exceedingly frugal—almost severe in its simplicity. Endowed with an unusually active mind, capable of grasping, comprehending and analyzing any subject which was submitted to him or which attracted his attention, he possessed also the gift of a graceful speech, with a large store of practical knowledge upon a great variety of subjects gathered by extensive observation and long experience.

Mr. Shinn was elected a Member of the Institution on the 3rd of February, 1891.

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[1] Trans. Am. Soc. C.E., vol. xii. p. 189.
[2] *Ibid.*, vol. xiv. p. 405.
[3] Trans. Am. Inst. Mining Engineers, vol. viii. p. 11.
[4] *Ibid.*, vol. ix. p. 293.
[5] *Ibid.*, vol. xii. p. 632.
[6] *Ibid.*, vol. xix. p. 674.

PETER WILLIAM WILLANS was born on the 8th of November 1851, at Roundhay, a suburb of Leeds. After a preparatory course of instruction at a dame's school he entered in January 1862 the well-known public grammar-school of that town, then under the head-mastership of the Rev. Alfred (now Bishop) Barry, D.D. During his somewhat slow progress through the three bottom forms young Willans received more than his fair share of caning, and it was not until he reached the upper-fourth that he began to show inclination for learning of any kind; when in the fifth and lower-sixth forms, however, his composition of Latin and Greek verse gave promise of a brilliant University career, had he not elected to join the scientific department of the school, in order to learn chemistry and the elements of natural philosophy. It was here that Willans first acquired a taste for science, but he often said in after years that it was only by hard reading at night, during the period when he worked as a draughtsman, that he mastered the theory of the steam-engine.

When he left school his father, who owned extensive woollen mills in Leeds, wished him to go into the cloth trade, but Willans was persuaded by an old schoolfellow, Mr. W. H. Massey, who had become a millwright, to try Mechanical Engineering. After serving a short probationary term, he was in 1867 apprenticed to Messrs. Carrett and Marshall, of Leeds, who were largely engaged in the manufacture of coal-cutting and other mining-machinery, organ-blowers, and hydraulic motors; and it was in connection with apparatus of this kind that he began to design improvements in valve-gear. He made working models of engines and pumps which were marvels of ingenuity, although not of any great practical value. A few months before he was out of his time the business of Messrs. Carrett and Marshall was transferred, in 1872, to the firm of Messrs. Hathorn, Davis, Campbell, and Davey; and from letters he wrote pending the negotiations it seems that he had great difficulty in making up his mind whether to stay with the new people, to go into partnership with a fellow-pupil, who offered Willans £5,000 "to put into anything," or to follow his old schoolfellow to the works of Messrs. John Penn and Sons, where there was an opening for a draughtsman at 30*s*. a week. He finally decided on the last course, because of the prospect of the two friends living together and helping each other, and commenced work in the drawing-office at Greenwich early in August, 1872, his first job being a pipe-drawing for two large ironclads ("Kaiser" and "Deutschland"), although he had never before seen a marine-engine. By sheer hard work he raised

himself above the level of his fellows, became exceedingly useful at trial-trips and gained the confidence and respect of those who were brought into contact with him. His leisure time was spent in reading and in drawing out Zeuner and other valve-gear graphics. In these studies he received later on considerable assistance from Mr. J. McFarlane Gray, Chief Examiner of Engineers to the Board of Trade, of whom he always spoke with gratitude.

While in the employment of Messrs. Penn, Willans invented, and patented in 1874, his three-cylinder steam-engine, in which the piston of one cylinder acts as the valve of another, the reversing being effected by moving a 6-port three-way valve from one position to another. The first engine of this type was made by Messrs. Penn, in whose possession it remains, after having been used on many occasions as an auxiliary in the smith-shop, in the pattern-shop and in a floating workshop. But the firm was not prepared to take up the manufacture of the Willans engine; a license was therefore granted to Messrs. Tangyes of Birmingham and the engine as turned out by them was largely used for various purposes at home and abroad. The failures were so numerous, however, that Willans left Messrs. Penn to join Mr. Alexander Ward, who had bought a share of the patents, and, as Willans and Ward, Consulting Engineers, to devote the whole of his time to try to make a success of the undertaking. When shortly afterwards Messrs. Tangyes, for commercial reasons, decided to withdraw from the matter, Messrs. Hunter and English of Bow were induced to make the Willans engine for marine purposes and eventually Mr. Willans himself was appointed in 1876 manager of this branch of their business. The English Admiralty and some foreign Governments made many trials with the improved engine, which he designed to work as 'compound,' and its applications in other directions were numerous and varied. During the four years 1876–1879, however, the hopes of all concerned were only partially realized; troubles with 'roller' and other bearings had not yet been entirely overcome and there was also some difficulty in dealing with Willans himself. His outdoor work took him very often to the reaches of the Upper Thames and, having taken up his residence at Hampton Wick, he found it increasingly difficult to give unremitting attention to the indoor work of a factory at Bow. In October, 1880, therefore, he left Messrs. Hunter and English and went into partnership with Mr. Mark H. Robinson, with whom he started works at Thames Ditton for the manufacture of his three-cylinder launch-engine and for building launches and steam-yachts.

When electric lighting was introduced into England, the want of a good high-speed steam-engine was much felt, and, at the advice of Mr. R. E. Crompton and Mr. W. H. Massey, Mr. Willans decided to adapt his engine to this class of work. The first public trial of one of his engines for electric lighting was in connection with a train-lighting experiment on the District Railway in January, 1884, and in the same year his firm supplied four 50-HP. engines for electrical work at Buckingham Palace. In 1885 the demand for larger engines of the high-speed type for central-station work induced him to undertake the design of an improved engine to compete in economy of steam with the highest class of slow-running engines; the Willans 'central-valve' engine was the result. Two years later, the building of launches having been practically abandoned, the growing importance of the business led to its conversion into a limited company, of which Mr. Willans acted as Chairman until his death. Thrown from his dog-cart on the morning of the 23rd of May, 1892, when driving to catch an early train, he received injuries to the brain, from which he died on the same day at his home at Frimley in Surrey.

Mr. Willans' great gifts as an inventor are well known, but his reputation will rest chiefly upon his experiments and researches on the economy of steam-engines. His thorough methods and the way in which he contrived to isolate in turn each doubtful point, or each neglected source of loss, stamped him as an original investigator of high order. He was elected a Member of the Institution on the 18th of May, 1886. In the previous year he had presented a Paper entitled "The Electrical Regulation of the Speed of Steam-Engines, and other Motors for Driving Dynamos,"[1] which gave rise to an instructive and interesting discussion, and for which the Council awarded him a Telford Medal and a Telford Premium. In 1888 he presented a Paper on "Economy Trials of a Non-Condensing Steam-Engine: Simple, Compound, and Triple,"[2] which elicited a valuable discussion and has since been referred to as a classic. For this he received a Watt Medal and a Telford Premium. Shortly before his death he sent in another Paper (supplementary to that read in 1888) which will be taken during the Session 1892–93. Of his personal characteristics it may be sufficient to say that while the most casual acquaintance would be impressed by his earnestness and manliness, those with whom he came much into contact soon learned to admire and respect him.

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[1] Minutes of Proceedings Inst. C.E., vol. lxxxi. p. 166.

[2] *Ibid.*, vol. xciii. p. 128 and vol. xcvi. p. 230.

Quick-witted and ready to pick out the weak points of an argument or scheme, he was always generous to opponents. He was a great skater and a keen fisherman, the attractions of a good trout stream being so strong that he would walk 10 or 12 miles, fish the whole day, and walk back afterwards, sometimes for three consecutive days. He was full of ideas for the benefit of his workmen and devised and adopted a system of profit-sharing, which completely identified their interests with those of the firm.

JAMES ALEXANDER BETTS, youngest son of the late Mr. Alexander Stewart Betts, was born in London on the 22nd of July, 1845, and was educated at Powis House School, Woolwich, on leaving which he studied telegraphy under his brother, Mr. A. S. Betts, then War Office Telegraphist at Woolwich Arsenal and now Superintendent of the Persian Gulf Cable at Karachi. In 1862 he entered the service of the Electric Telegraph Company and in October, 1863, was transferred to the Submarine Telegraph Company, with which he remained until January, 1865. From that time he did little work until September, 1870, when he was appointed an Inspector in the Engineering Department of the Postal Telegraph Service and stationed at Oxford. Promotion being slow, he resigned in October, 1873, and joined the India-Rubber, Gutta-Percha and Telegraph Works Company as Telegraph Engineer. He studied torpedo work and obtained a certificate from the School of Submarine Mining at Chatham and in October, 1874, entered into an agreement, through the India-Rubber Company, with the Chinese Government to take charge of the Torpedo Service of that Empire.

Mr. Betts acted as Chief of the Chinese Torpedo Service until December, 1879, during which time he planned and carried out the torpedo defences of the Taku Forts and constructed the first telegraph line opened to the public, from Tientsin to Taku, a distance of 47 miles. China, with a coast line between 2,000 and 3,000 miles in length and with many large navigable rivers, is dependent to a great extent on submarine mining for defence against an aggressive fleet. After successfully conducting a series of experiments at Tientsin in 1875 before Li Hung Chang, Viceroy of Chih-li and Secretary of State for War, Mr. Betts was directed to form a School of Submarine Mining. Twenty-four native students, chiefly from the official classes, were obtained and after four years' instruction became so efficient as to form the nucleus of the various torpedo and telegraph departments which have since

been established throughout the empire. It was they who assisted in the construction of the line from Tientsin to Taku above referred to. While at Tientsin he bought for the Chinese Government its first torpedo-boat, a steel steam-launch carrying three spar-torpedoes, and built several spar torpedo-cutters which were manned by native sailors.

At the end of 1879 Mr. Betts returned to England and in April of the following year re-entered the service of the India-Rubber, Gutta-Percha and Telegraph Works Company, which in September, 1881, sent him back to China as its representative. In May, 1883, having been severely wounded in the hand by a sword-cut, he again returned to England, intending to settle down to a quiet country life. A few months later, however, he received a telegram from Chang Shu Sheng, Viceroy of the Liang-Kuang, to return at once and undertake the defence of Canton, in anticipation of war between China and France. A most interesting account of the works he there carried out is given in a Paper entitled "The Torpedo Defence of Canton during the Franco-Chinese War in the years 1884–85," an abstract[1] of which was published by the Institution of Electrical Engineers, of which Mr. Betts was a Member. For his services on this occasion he was created a Mandarin of the third rank and received other marks of appreciation from the Imperial Government, and from the merchants of Canton a valuable silver urn. Unfortunately, however, his health suffered severely from the arduous nature of this work and he was obliged to return to England in 1887.

In the following year, his health being to a certain extent re-established, Mr. Betts accepted the appointment of Manager of the India-Rubber Company's branch at Calcutta, which post, however, he was not destined to occupy long. After three years of hard and up-hill work, and just as the agency was becoming valuable, his health suddenly failed; an attack of inflammation of the liver, following low fever, proved fatal, and he died on the 25th of July, 1892, at the comparatively early age of 47. Mr. Betts' reputation as an engineer in China was considerable and for many years he enjoyed the personal friendship of some of the highest officials of the empire. Long residence enabled him to speak the language fluently and embued him with a taste for Chinese literature and art, evidence of which was afforded by his large and valuable collection of curios and pottery. He was elected an Associate Member of the Institution on the 6th of March, 1883.

[1] Journal Inst. Electrical Engineers, vol. xix. p. 199.

ANDREW AITKEN HADDIN, son of the Rev. John Haddin, was born at Glasgow on the 19th of April, 1849, and was educated at Rothesay and at Glasgow University, where he passed through the Engineering curriculum. He studied hard, took a good position in the classes, and obtained the certificate of proficiency in Engineering Science. In 1867 he was for some six months in the employment of Messrs. Kyle and Frew, Land Surveyors, of Glasgow, and was then articled to Mr. W. R. Copland for three years, during which time he gained experience on the Dumbarton Waterworks, on the water-supply of Innellan and of Callander, on the Bill for acquiring Glasgow Gasworks, on the arbitration as to the Dundee Gasworks, and on various other undertakings.

In 1870 Mr. Haddin started business on his own account, turning his attention chiefly to works for water-supply and making numerous surveys and reports, which led to his being entrusted with the construction of works at various places, the more important being Largs, Hogganfield, Bishopbriggs and Auchenairn. In addition to water-supply for domestic purposes, he was engaged in the construction of works at many large manufactories in the neighbourhood of Glasgow. He also designed several buildings, both public and private, which were erected under his supervision. In 1882 he entered into partnership with Mr. Thos. O. Niven. Among the works designed and carried out by the firm may be mentioned the water-supplies of Lennoxtown, Dailly, Lockerbie, Tarbert, Lochwinnoch, Moffat, Neilston and Milnathort, and the drainage of Prestwick, Tarbert and Lockerbie. He was also occupied in the design and construction of an esplanade and pier at Millport on the Clyde and of several important buildings for manufacturing and other purposes; prepared, for the promoters of the undertaking, drawings, specifications and estimates for a large slip dock at Chaguaramas Bay in Trinidad; and from time to time was engaged on railway and harbour works. He devoted himself entirely to business until the spring of 1892, when his health becoming seriously impaired, he sought rest and change in the country, but, as his strength did not rally, returned home and passed peacefully away on the 1st of October, 1892.

Mr. Haddin was extremely active and possessed great aptitude for detail, and his work as an engineer was always carefully thought out and executed. Sincere and straightforward, and of a genial nature, he made many friends both in business and in private life. He was elected an Associate Member of the Institution on the 2nd of December, 1890.

CHARLES REMFRY, fourth son of the late Mr. William Remfry, Mining Engineer, was born at Charlestown in the parish of St. Austell, Cornwall, on the 29th of May, 1837. His family having removed to Germany, he was educated at private schools at Stollberg and at Vilvorde in Belgium, and at seventeen years of age was articled to his father, who was then Manager of the mines near Stollberg belonging to the Eschweiler Mining and Smelting Company. In June, 1856, being then only nineteen years of age, he was appointed Manager of the Breinigerberg Lead Mine, one of the largest owned by the Company, and in the following year succeeded his father, who had retired from the Company's service in order to take charge of more important mines in another part of Germany.

Mr. Remfry held this post at Stollberg until 1862, when he left Germany for Spain, to take up an appointment as Manager of the works of the San Roque Lead Mining and Smelting Company in Linares, a district at that time in its infancy. He soon introduced pumping-machinery and modern appliances, then unknown in the district, and worked the mines on more scientific principles. The machinery had to be brought great distances in carts over bad roads, and Mr. Remfry may justly be considered as the pioneer of English mining industry in that part of Spain. About 1868, however, the San Roque Company ceased operations and his connection with it came to an end. He then undertook the management of several mines in the district, among which may be mentioned the Ricas y Verdades, Los Alemanes, Majada-Honda, and San Miguel, and in April, 1872, he accepted the post of Mining Engineer to Messrs. Heredia, at that time owners of some of the most important mines in Linares. Finding, however, that his health was suffering from overwork, he resigned this appointment in June, 1876, and also gave up the management of several of the mines with which he had been connected.

At the request of Mr. Andres de Pereda, Mr. Remfry then undertook to superintend the development of the San Miguel group of mines, which by careful and energetic management he succeeded in advancing to a prominent position in the district. Among other improvements he introduced was the laying down of plant for rock-drilling and winding-machinery driven by compressed air. His connection with these mines lasted until his death, which took place at Linares on the 5th of September, 1892, from Bright's disease.

Mr. Remfry enjoyed a high reputation as a Mining Engineer, and his genial disposition and good qualities won for him the esteem and regard of a large circle of friends. He was elected an Associate of the Institution on the 2nd of December, 1873, and was transferred to the class of Associate Member on its creation in December, 1878.

MATTHEW HENRY SIMPSON, son of Mr. Matthew Simpson, of Lancaster, was born on the 12th of August, 1853, and was educated at Birkenhead Proprietary School. After serving articles for six years in the engineering department of Messrs. Laird Brothers of Birkenhead, he became in 1879 managing partner in the firm of Messrs. Sharpe & Co. of the Phœnix Foundry, Lancaster. Feeling in the management of that foundry the lack of theoretical knowledge, he entered the metallurgical laboratory of the Royal School of Mines, where he passed the examinations in a highly satisfactory manner. Having a decided taste for original research, he spent a large portion of his time on returning to Lancaster in metallurgical investigations, more particularly in connection with the properties of iron and steel.

Mr. Simpson's work at the Phœnix Foundry ceased in 1886, when he dissolved partnership. He then continued his metallurgical studies at the Royal School of Mines and in 1887 became Assistant to Mr. Charles Appleby, Mining Engineer, with whom he remained for some eighteen months, his time being devoted to the design of machinery and to the metallurgy of the precious metals. In dealing with processes for the extraction of gold from its ores by chlorine or by bromine, he realised the difficulty of transporting those materials and devised and patented a process for transporting bromine in a solid form.[1] He had previously taken out, in conjunction with Mr. Francis Sharpe, a patent[2] for a machine for breaking pig-iron.

At the beginning of 1889 Mr. Simpson went to British Guiana as Managing Engineer to the Demerara Gold Association, a company engaged in mining alluvial gold deposits. In the summer of the following year he returned to England on the conclusion of his agreement with that Association, but shortly

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[1] Official Journal of the Patent Office, 1888, No. 17,930.

[2] *Ibid.*, 1885, No. 4,605.

afterwards went back to British Guiana to take charge of an exploratory expedition which he himself had organised and fitted out. Unfortunately, however, he fell a victim to the unhealthy climate and died on the 29th of February, 1892.

Mr. Simpson's enthusiasm for work and his genial manners and keen sense of humour made him very popular with all who knew him. He was elected an Associate Member of the Institution on the 3rd of March, 1891.

WILLIAM UPTON TINNEY was born in 1824 and at twenty-two years of age entered the service of the Chartered Gas Company, where he was engaged at Brick Lane and Goswell Street stations for nearly twelve years and attained the position of second in the Rental Office. In September, 1858, he was appointed Engineer and Manager to the Winchester Water and Gas Company, which appointment he held for nearly thirty-four years. During that time the remodelling of the waterworks and the entire renewal of the gasworks were carried out under his superintendence. This involved new wells, pumps, boilers, engines, reservoirs, buildings and mains for the water-supply; and new retorts, holders, plant, buildings and mains for the gas-supply: indeed both water- and gasworks were practically rebuilt and doubled in size.

Mr. Tinney retired from the service of the Winchester Water and Gas Company shortly before his death, which took place at Bournemouth on the 10th of October, 1892. His practical ability and sound judgment, combined with an amiable and just disposition, made him generally liked and respected. He was elected an Associate of the Institution on the 4th of December, 1877, and was transferred to the class of Associate Member on its creation in the following year.

*** The following deaths have also been made known since the 19th of August, 1892:—

Honorary Member.

Siemens, Dr. Werner von; *born* 13 December, 1816; *died* 6 December, 1892. (*Inflammation of the lungs.*)

Members.

CRACKNELL, EDWARD CHARLES; *born* 22 May, 1831; *died* January, 1893.

FARRELL, JAMES BARRY; *born* 3 December, 1810; *died* 3 January, 1893.

GORDON, JAMES EDWARD HENRY; *born* 26 June, 1852; *died* 3 February, 1893. (*Fall from a horse.*)

GROVER, JOHN WILLIAM; *died* 23 August, 1892, *aged* 56.

HIGGIN, GEORGE; *born* 16 January, 1833; *died* 8 November, 1892.

JONES, JOHN HODGSON; *born* 29 April, 1823; *died* 1 December, 1892.

MARTEN, HENRY JOHN; *born* 3 February, 1827; *died* 3 November, 1892. (*Paralysis.*)

PAULING, HENRY JOHN; *born* 1821; *died* 8 September, 1892.

TAUNTON, JOHN HOOKE; *born* 8 April, 1821; *died* 31 January, 1893.

Associate Members.

CAZIMAJOU, JOSEPH JULIUS, B.Sc.; *born* 10 February, 1846; *died* 4 August, 1892.

CLARKE, GEORGE HOWARD; *born* 5 September, 1849; *died* 9 March, 1892. (*Yellow fever.*)

DOUGLAS, JOHN; *born* 20 March, 1836; *died* 10 January, 1892. (*Aneurism of the heart.*)

GODWIN, HENRY COLTHURST; *born* 18 September, 1858; *died* 25 December, 1891. (*Yellow fever.*)

HARVEY, HENRY NICHOLAS; *born* 3 June, 1857; *died* 14 December, 1892. (*Lung disease.*)

HODGES, EDWARD; *born* 5 January, 1844; *died* 8 December, 1892.

HOPKINSON, CHARLES HERBERT; *born* 15 July, 1858; *died* 27 September, 1892.

LANE, GEORGE MORGAN; *born* 31 May, 1856; *died* 24 October, 1892. (*Yellow fever.*)

PERRY, ALFRED; *born* 1834; *died* 12 December, 1892. (*Heart disease.*)

SLAGG, CHARLES; *born* 31 August, 1823; *died* 23 January, 1893. (*Heart disease*).

VERNON, HERBERT CHARLES ERSKINE; *born* 28 September, 1851; *died* 15 February, 1893.

WILLIAMSON, JOHN RICHARD HUTCHINSON; *born* 6 August, 1859; *died* 8 December, 1892. (*Lung disease.*)

Associates.

ARCHDEACON, *Staff-Captain* WILLIAM EDWIN, R.N.; *born* 6 January, 1839; *died* 23 January, 1893. (*Heart disease.*)

CALVER, *Captain* EDWARD KILLWICK, R.N. (retired), F.R.S.; *born* December, 1813; *died* 28 October, 1892.

CARPMAEL, ALFRED; *born* 9 February, 1835; *died* 1 February, 1893. (*Dropsy.*)

FARMER, JOHN STINSON; *died* 12 December, 1892, *aged* 65.

GROVER, *Colonel* GEORGE EDWARD, R.E. *born* 2 June, 1840; *died* 29 January, 1893. (*Heart disease.*)

KUNHARDT, *Major* HENRY GEFFEKEN, R.E.; *born* 6 November, 1850; *died* 4 November, 1892. (*Dysentery.*)

ROWAN, FREDERIC CHARLES; *born* 28 August, 1844; *died* 11 December, 1892. (*Pneumonia.*)

SOMERVILLE, JOHN; *died* 15 December, 1892, *aged* 59.

Information respecting the life and works of any of the above is solicited in aid of the preparation of Obituary Notices.—SEC. INST. C.E., 20 February, 1893.

Sect. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

Conchyloid Level. By Captain Gentil.

(Revue d'Artillerie, Sept. 1892, p. 220.)

In a previous number of the "Revue,"[1] the Author describes a novel level for artillery use, the object being the construction of an instrument such that:

1. The angle formed by the axis of the spirit-level tube with the base of the instrument may be determined by direct reading on a single graduated limb, without vernier;
2. The precision of the instrument shall be to 1′;
3. It shall be as easy to measure a given angle as to obtain it.

It is laid down as a necessary condition that the divisions on the graduated arc shall be not less than $\frac{1}{2}$ millimetre, or 0·02 inch apart, and that consequently to obtain a precision of 1′ on a circular scale marked with such divisions, the radius of the arc must equal 5 feet 7·63 inches, and that even with the representation of 10′ by each division of 0·02 inch the necessary radius would be 6·76 inches, showing that a level constructed on the usual model would, even with a low degree of precision, be unwieldy in size.

The elementary principle of the Author's level is the use of a circular disk pivoted at one point of its circumference to the point on the base of the instrument, intersected by the arc traced by the spirit-level. The latter is extended and rests on the disk, forming a tangent line to such part of the periphery of the circle as may by its rotation about its fixed point be for the moment uppermost. The length of the spirit-level from its pivoted joint, marked "C" on the illustrative diagrams, to the rotating point of the circular disk "A," is so arranged that by the rotation of the disk through 180° + 45° the extended end of the spirit-level is raised through an angle of 45°. The length of the line AC, or spirit-level carrier, being fixed at 100 millimetres, or 3·93 inches, the length of the arc travelled by a radius of the circular disk will be 10·92 inches, or 555·4 divisions of $\frac{1}{2}$ millimetre, or approximately 0·02 inch, thus allowing 4 feet 9 inches per division without vernier, and by the use of a circular graduated limb of a radius of 2·76 inches.

The Author then develops his idea by showing diagrams of a

[1] Revue d'Artillerie, June 1892, p. 220.

construction reducing the adjustable opening of the instrument to 22° 30′, but for measuring or obtaining angles between 22° 30′ and 45°, the base used when measuring less than 22° 30′ is, together with the attached spirit-level carrier, raised through exactly that arc by means of a solid angle fitted to the first base. By these means a precision of 2 feet 5 inches may be obtained, using a circular disk of slightly less dimensions than in the first instance. The adjustable opening of the apparatus may be still further reduced to 15°, and two solid angles of 15° each provided each with its base for use in obtaining angles between the corresponding limits. By the use of a purely circular disk for raising the spirit-level carrier, the angle formed by the latter and the base of the instrument does not vary proportionately with the rotation of the disk. It is necessary, therefore, to obtain such a curve as, when used in place of a true circle, will obviate this difficulty. The Author gives full geometrical and practical determinations of the shape of such curve, to which he gives the term conchyloid, and which is distinguished by a constantly increasing radius.

In further developing the foregoing principles, the curved disk is extended so that its radius, instead of describing somewhat over a half revolution, makes a complete revolution whilst raising the predetermined angle, and the Author shows by diagrams and explanation that the disk-curve may be so modified as to obtain the travel of the spirit-level carrier by two, three, or more complete revolutions of the disk.

The consideration of the practical shape of the apparatus is then proceeded with by the Author. The most desirable dimensions are 3·93 inches between the two fixed rotating points A and C respectively, that of the spirit-level and base and the pivoted point of the curved disk. The expanded radius of the latter travels over a circular scale having a radius of 3 inches, giving a precision of 1 foot for each mark on the scale, whilst raising the spirit-level through 15°.

The final type constructed by the Author has, however, an adjustable opening of 30° with a solid angle of 30° attached thereto; this gives for each mark on the scale a precision of 2 feet, but it is claimed that with a scale marked with degrees 0·02 inch apart the eye is quite capable of setting the pointer or extended radius of the curved disk midway between any two scale marks, thus increasing the real precision to an angular measurement of 1 foot.

In addition to diagrams illustrating the principles of the apparatus, a plate of figures is given of the details of the level constructed by the Author.

F. E. B.

Cost of Levelling in Germany. By — Gerke.

(Zeitschrift für Vermessungswesen, 1892, pp. 329 and 433.)

With a view to affording accurate information of the cost of survey work in Germany, the Author gives complete details of the primary levelling for the Altenburg Waterworks and for the Saale Conservancy.

1. The levels for the Altenburg Waterworks were connected with four bench-marks of the Ordnance Survey of Saxony, the connecting lines being altogether 22 kilometres (13 miles) in length, whilst the actual length twice levelled was 39·4 kilometres (23½ miles). With regard to the degree of accuracy demanded, the regulations of the Prussian Ordnance Survey were followed, according to which a levelling is regarded as good if the mean error does not exceed 3 millimetres per kilometre (0·7 inch per mile), and as passable if the mean error does not exceed 5 millimetres per kilometre (1·18 inch per mile). The levelling was conducted for the most part over well-made roads and footpaths, only short distances being taken over meadow land. In some cases the gradients were considerable, the highest bench-mark being 276 metres (905 feet) and the lowest 198 metres (650 feet) above sea-level. On the whole, however, the ground may be regarded as extremely favourable for levelling operations. The preliminary work consisted in the selection of bench-marks; altogether fifty-one were chosen, of which thirty-seven were marked by means of iron bolts. The weather was unfavourable, the fieldwork taking place from October 10th to 21st, and from November 2nd to 7th. The levelling instrument used had a telescope 46·5 centimetres (8¼ inches) in length, and the two staves employed were of the pattern used on the Prussian Survey, reading directly to 5 millimetres (0·2 inch). The figuring on each staff was in accordance with Nagel's plan, the front side being numbered from bottom to top and the rear side from top to bottom, with a constant sum of the readings on the two sides of 6·1 metres. Two iron plates weighing 10 lbs. each and a large umbrella with light tripod stand also formed part of the equipment. For transporting the instruments a light hand-barrow was used. The mode of conducting the levelling was as follows:—

Having set up the instrument midway between the two staff-holders, A and B, the observer reads the back-sight at A first on the front side and then on the rear side of the staff. The clerk notes these two readings in a field-book specially ruled for this method, and at once mentally adds them up; if the sum agrees with the constant on the staff (6·1), no serious error has been made. The staff-holder A then, at a given signal, leaves his station and moves on, while the observer makes the two readings on the forward staff held by the man B. In the meantime the

man A has reached the station at which the instrument is set up, where he finds the barrow and takes it on to the next station for the instrument. If the reading on the forward staff is found to be correct, the observer carries on the instrument to the next station, whilst the clerk brings on the tripod and sets it up, levelling it by the aid of a circular spirit-level in the tripod-head. The length of the line of sight is determined by pacing, and is noted at each station. In this way the work proceeds, the barrow for the instruments being taken from station to station by the two staff-holders alternately. The fieldwork occupied fourteen days, averaging seven working hours per day. Office work occupied a clerk and an assistant-surveyor four days each, and the director of the survey three days. Thus in fourteen days a length of 78·9 kilometres (47 miles) was levelled, the distance levelled each day varying according to the weather from 0·9 to 10·7 kilometres (0·54 to 6·4 miles), and averaging 5·6 kilometres (3·35 miles). Altogether the instrument was set up one thousand and one times, the average distance between the staves being 78·8 metres (258 feet), and the average length of the lines of sight being 39·4 metres (129 feet). The shortest line was, under exceptional circumstances, 15 metres (49 feet), whilst none was longer than 50 metres (164 feet). The number of times the instrument was set up per day varied from 17 to 130, the average being 71·5.

In determining the cost of the levelling, account has to be taken (1) of the cost of the bench-marks, (2) of the salaries and wages for field and office work, and (3) of miscellaneous expenses. In putting in thirty-seven iron bench-marks and in cutting fourteen crosses, a mason was occupied for seventy-nine hours, and during fifty-one hours was assisted by a labourer. As wages, the former received 32*s.* and the latter 13*s.* 7½*d.*, whilst the outlay for travelling expenses and material amounted to 6*s.* The cost of putting in an iron bench-mark was 1*s.* 2*d.*, and that of cutting a cross 7*d.* The iron bench-marks of cast-iron bolts, with turned and copper-plated heads, cost 4*d.* each. Thus the total cost of the fifty-one bench-marks was £3 4*s.* 7*d.* Besides travelling expenses, the surveyor received a salary of £6 5*s.* to £7 10*s.* per month with 4*s.* 9*d.* daily for field expenses, whilst the clerk received £3 15*s.* per month and 2*s.* to 3*s.* daily for expenses. The staff-holders received 2*s.* 6*d.* per day and 1*s.* for expenses. The miscellaneous expenses include transport of the instruments, drawing materials, and postage. The total cost of the levelling was therefore :—

	£.	s.	d.
For fixing bench-marks	3	4	7
Salaries, wages, and expenses—			
(*a*) For field work	19	10	6
(*b*) For office work	5	0	0
Miscellaneous expenses	1	3	2
Total . . .	28	18	3

Thus the total cost of twice levelling one mile amounted to 25*s.*

2. The second levelling of which the Author gives particulars was made in connection with a geodetic and hydrometric survey authorised by the Government of the Duchy of Saxe-Altenburg for the Saale Conservancy. With a view to obtaining levels for contour lines, a large number of fixed points had to be determined in the vicinity of the river. The total length twice levelled amounted to 63·30 kilometres (38 miles). No special levelling instrument was employed, the work being performed by means of the theodolite used for the trigonometrical survey of the district. Two staves were used, graduated in centimetres on the front side from 0 to 300 from bottom to top in erect black figures, and on the rear side from 300 to 600 from top to bottom in inverted red figures. The constants of the two staves were 601·07 and 601·11 centimetres respectively. The surveyor had an assistant, a clerk, two staff-holders, and a labourer. The mode of procedure was as follows :—

The instrument having been set up midway between the two staves, the surveyor directed the telescope to the back staff A and observed the reading at each of the three horizontal wires. The telescope was then turned to the forward staff B and the three readings observed. At a given signal the staff-holders then turned the staves, and the three readings on the staff A, and afterwards on the staff B, were taken. Thus there were on each side of the staff three readings, or twelve readings for each station. The clerk entered the readings dictated to him in the field-book, and at once determined by calculation that there was no serious error in the readings. Besides acting as a check on the accuracy of the observations, the readings on the top and bottom wire served to give the distance between the two staves. The levelling was conducted by two surveyors working simultaneously, one on the section from Weimar to Göschwitz (A), and the other on the section from Göschwitz to the frontier of the Duchy (B). The particulars of the two sections were as follows :—

	A.	B.
Total length	37·4 miles	41·00 miles.
Average distance levelled per day .	1·34 mile	1·33 mile.
Number of times the instrument was set up	673	877
Average length of line of sight . .	155 feet	128 feet.
Cost of levelling 1 mile	42*s.* 6*d.*	41*s.*

This estimate does not include the cost of correspondence, fixing bench-marks, the prime cost and depreciation of the instruments, nor the cost of organization.

B. H. B.

Theodolite for Shaft-Surveying. By W. Breithaupt.

(Osterreichische Zeitschrift für Berg- und Hüttenwesen, 1892, vol. xl. p. 251.)

For shaft-surveys a mining transit-theodolite is the instrument generally employed, a diagonal eye-piece being inserted, or the telescope being taken out of its bearings and replaced by an eccentric telescope with axis and vertical circle. Either of these methods has its disadvantages. The diagonal eye-piece is difficult to adjust, and its position in relation to the line of sight is rarely constant. Moreover, the search for the object to be sighted is inconvenient and causes a waste of time. The eccentric telescope is expensive and inconvenient to transport. In both cases it is difficult to make the change underground, and damage is easily possible. For these reasons the Author has constructed a mining transit-theodolite, a drawing of which accompanies his paper. In this an auxiliary small but powerful telescope is attached to one end of the horizontal axis with a counterpoise at the opposite end. This telescope carries a spirit-level, and is provided with fine adjustment, so that it is possible to bring the line of collimation into exact coincidence with that of the main telescope. The illumination of the field of both telescopes is effected through the axes, a small adjustable mirror being placed in the centre of each telescope.

B. H. B.

Comparative Experiments on the Strength of Metallic Chains. By Professor Hartig.

(Der Civilingenieur, 1892, p. 477.)

The following Table contains the leading results of tests of chains of various kinds, carried out partly under the supervision of the Author and partly by others.

The equivalent elastic length (*Traglänge*) is the length which would be necessary to strain the chain to the elastic limit by its own weight.

Similarly the equivalent breaking length (*Reisslänge*) is the length which would be required to rupture the chain by its own weight.

These quantities, together with the "specific work of rupture," are frequently employed in Germany as a criterion of the character of a test-piece.

The original contains a supplementary Table, compiled by the Author on the assumption that the elastic limit of each chain has been raised by repeated tests to two-thirds of the breaking strength, as is usual in the case of heavy chains.

The tabulated results are selected by the Author from the more numerous examples recorded in the text of the original.

—	Weight per Foot.	Equivalent Elastic Length.	Equivalent Breaking Length.	Elongation at Elastic Limit.	Elongation at fracture.		Specific Work of Rupture for Unit Weight (1 lb.).	Ratio of		
					Total.	Elastic.		Tensile Strength	Total elongation	Specific work of Rupture
								of chain to that of bar of Raw Material, of equal minimum cross-section.		
	Lbs.	Feet.	Feet.	Per cent.	Per cent.	Per cent.	Foot-Lbs.			
1. Clock chain, steel wire.	0·041	1,145	2,027·50	1·48	48·50	2·62	875·760	0·0726	5·16	0·858
2. Loom chain, „ „ .	0·222	..	1,430·83	..	13·25	..	793·760	0·0861	5·15	0·401
3. „ „ , iron „ .	0·0079	537·5	968·33	..	52·20	..	469·040	0·0485	3·06	0·165
4. "Vaucanson" chain, steel wire.	0·405	777·5	1,840·83	1·12	34·00	2·74	547·76	0·110	2·57	0·276
5. "Ewarts" driving chain, malleable cast-iron . .	1·572	..	2,335·83	..	9·94	2·10	367·36	0·138	1·00	0·753
6. Ordinary chain . . .	8·790	1,630·83	6,391·66	0·2	20·00	8·80	895·44	0·397	0·715	0·220
7. "Gladstone's" chain, brass wire	0·227	..	9,450·00	..	19·64	..	1,111·92	0·633	0·569	0·267
8. "Gladstone's" patent chain, brass sheet . .	0·071	..	7,183·33	..	32·80	0·37	1,590·80	0·719	1·49	0·895
9. "David's" patent chain, mild steel.	10·872	2,880·83	8,925·00	3·27	12·50	10·13	859·36	..	..	..
10. "Oury's" steel chain, made out of a single rolled bar.	9·542	..	10,791·66	..	14·10	..	..	..	..	..
11. Pitch chain, wrought-iron	5·825	..	1,664·16	..	0·69	0 28	6·626	..	..	..

G. R. B.

The Cement Laboratory of the St. Louis Waterworks Extension.

By S. B. Russell.

(Engineering News, New York, vol. xxv., 1892, p. 2.)

The testing of the cement used in the St. Louis waterworks extension was carried out on the lines laid down in the report of the committee of the American Society of Civil Engineers on that subject.[1] The bulk of the cement used was Portland, which arrived on the work in shipments of from one thousand to five thousand barrels. The barrels were numbered consecutively in groups of three, *i.e.* three barrels received the same number, and one barrel of each three was sampled. The group of three was treated as one barrel. In the case of brands of cement of known quality only the odd or even numbers were tested. Each sample was taken large enough for two briquettes in order that check tests might be made in case of low results.

The cement was tested neat, and most of the mixing was done by means of a machine called a "jig," of which drawings are given. The principle of the machine is a simple one. Sufficient cement to form one briquette is put into a cup, the proper proportion of water is poured on the cement, and a tight-fitting cover put on. The charged cup is then shaken violently at the rate of from 500 to 800 oscillations per minute until the cement and water are thoroughly mixed. The frame upon which the cups are fixed moves vertically, and is actuated by a crank. The cups themselves are of brass with covers ground to fit accurately, and on the top of the covers a steel plug is inserted to withstand the abrasion of the tightening screws. The inside of both cup and cover is finished very smooth so that the cement will not adhere.

The cement is first passed through a coarse sieve to remove chips and similar impurities, and 135 grains are weighed into each cup; 8 drachms of water are then measured and poured into each cup. The cups having been fixed upon the jig by means of thumb-screws, the fly-wheel shaft is turned at a rate somewhat exceeding 500 revolutions per minute for about a minute and a half. The contents of the cups are then found to have formed plastic balls quite soft on the surface, but of a consistency like soft putty within. The balls are pressed into the mould with the fingers, and smoothed off with a knife. With the aid of this jig two men can turn out two dozen briquettes an hour. The proportion of water required being less than with hand mixing, a slightly larger quantity of cement is required to fill the briquette moulds, and this produces a somewhat higher tensile strength of the finished briquette.

Nearly all Portland cement was mixed with 20 per cent. of its

[1] Minutes of Proceedings Inst. C.E., vol. lxxxv. p. 413.

weight of water, and it is one advantage of this method of mixing over hand work that none of the water can evaporate during the process. The cement is mixed neat; but new brands of cement and cements not showing a high neat test are subjected to a twenty-eight-day sand test, the composition of the briquettes being 1 part of cement to 3 parts by weight of sand.

A "trip hammer" is also used for making briquettes, and is similar to that in use in Germany for the same purpose. The hammer is worked by a hand-crank, and is provided with automatic counting-gear which stops it after one hundred and fifty blows. The hammer falls upon a plunger roughly fitting the briquette mould; the cement is gauged by hand and placed in the mould. After receiving one hundred and fifty blows from the hammer, the briquette is shaved off with a knife and at once removed from the mould.

The state of the briquettes indicates whether too much or too little water has been used in making them. The temperature of the testing-room in which the briquettes are kept is maintained as nearly as possible at 60° Fahrenheit. The shape of briquette used is that known as the American Society standard. The sides of the clip are hinged, and are connected by a cross-bar in such a manner that they can adjust themselves. Two brass index-points show whether the strain on both sides of a briquette is equal. Since this clip has been in use the briquettes rarely break at any other point than their smallest section.

W. F. R.

Sidero-Cement (*Bordenave System*). By Henri Mamy.

(Le Génie Civil, vol. xxi., 1892, p. 189.)

The system of construction to which the above name has been given, is applied to the manufacture of pipes and reservoirs for water. It consists in the employment of a framework of iron bars embedded in cement-mortar, in the manner which has long been used for floors. In pipe-making, bars of I section are used, as long as possible, wound into a helical form. The pitch is determined with regard to the section employed and the pressure in the pipe, so that the iron helix will have sufficient strength alone to resist the pressure. The working-stress for the purpose of this calculation is taken as 9·8 tons per square inch. Thus for a pipe of 2 feet 7½ inches inside diameter, using a bar of about ½ inch in height by ⅛ inch in width, and weighing 0·14 lb. per lineal foot, the requisite pitch of the screw is 3·8 inches for a head of water of 33 feet. The results of this calculation are justified by experiments made on a line of piping of 4 miles in length.

The coefficient of expansion of iron and cement are so nearly the same that there is no danger of cracks from unequal expansion.

Pipes made on this system and shown at the Paris Exhibition in 1889, have been exposed to all the changes of weather since that time, and are in perfect condition.

Among the advantages claimed for this system for water-works, are that the metal is protected from deterioration, being everywhere embedded in cement, and that no vegetation or deposit of any kind occurs on the cement in any climate. With the line of piping above referred to (where the cement was nearly $1\frac{1}{2}$ inch in thickness), there was a slight leakage at first which rapidly diminished and became insignificant; in this respect the system is said to be superior to any iron piping with lead or other joints.

There is said to be a saving in cost over cast- or wrought-iron piping of 15 to 45 per cent., according to circumstances.

In this system a cylindrical reservoir is treated as a large pipe closed at one end. The floor is formed by a framework of radial and circumferential bars, and verticals are placed at intervals all round the wall, solidly attached to the floor. The pitch of the helix diminishes from the top to the bottom of the reservoirs to suit the increasing pressure.

Details are given of the special machinery for making these pipes, and the article is fully illustrated by engravings in the text and two full-page plates.

C. F. F.

Foundations on Natural Ground.

By Professor V. J. Kurdjümoff.

(Der Civilingenieur, 1892, p. 293. 13 Figs. and 1 Plate.)

The Author confines his attention to foundations in loose or sandy soil. There are, he states, only two treatises on the subject worthy of note, those of Rankine and Pauker. Pauker's theory is based on the mutual action of sliding and resistance prisms, while Rankine's is based upon the modern theory of granular masses. Jankowski's modification of Pauker's formula gives results which agree very well with experiment, but, nevertheless, is not based on assumptions which represent the phenomena actually occurring. The resistance and sliding prisms are assumed to have plane slide-surfaces, whereas in reality the latter are curved.

According to the modern theory of granular masses, if radii are drawn in every possible direction from any element of the mass, and the pressure on this element in each direction is plotted on the corresponding radius from the centre, then the points so obtained lie in the surface of an ellipsoid, the three axes of which are in general unequal. The Author's experiments have shown that Rankine's formula, based upon the preceding theory, does not give accurate results. This is because it involves the inad-

missible assumption that the difference in the pressures on two adjacent elements can be finite. From a theoretical consideration of the subject, which it would be impracticable to follow without the aid of illustrations, the Author shows that the slide-surfaces are probably defined by continuous curves starting vertically from the edges of the foundation, passing under the latter and out to the surface of the ground at the opposite side. To ascertain the actual form of the slide-surfaces a series of experiments was carried out in such a manner that the results could be photographically recorded. A box, having a glass side, was filled with sand, and a rectangular block of wood (representing a wall) pressed down by means of a screw upon the sand, and guided in such a manner as to have one surface in contact with the face of the glass. A visible cross section of the material was thus obtained, and was photographed by means of magnesium light. The experimental results confirm generally the Author's theoretical deductions. When the pressure was exactly vertical, the sand gave way on both sides of the block. The curves of the slide-surfaces were symmetrical with respect to the vertical axis, starting from the middle of the foundation. With an increase in the depth of the foundation, the outer portions of the slide curves became steeper, so that the width of the prisms of disturbed material measured perpendicularly to the sides of the block was not proportional to the depth of the foundation nor to the resistance. When the pressure deviated to a certain extent from a vertical direction, the disturbance of the sand sometimes occurred on one side only.

By giving various slopes to the surface of the sand, the form of the slide curves was correspondingly modified. The curves were also affected by a difference in the height of the surface on opposite sides of the block; in the latter case, from the observed phenomena, the Author arrived at the following rule: The width of the displaced prism is inversely proportional to the depth of the foundation on either side.

A vertical wall in close proximity to the block, was found to increase the resistance of the foundation, and to act in a manner similar to a difference in the height of the surface on opposite sides of the block.

The Author concludes with a discussion of the relative merits of the photographic method of observation as compared with that adopted by Forchheimer in conducting similar investigations, which latter method consisted in the use of alternate coloured and uncoloured layers of sand.[1] The original is accompanied by a Plate, containing reproductions of the photographic records, as well as by figures in the text.

[1] Minutes of Proceedings Inst. C.E., vol. lxxii. p. 331.

G. R. B.

Some Disputed Points in Railway-Bridge Designing.

By J. A. L. Waddell, M. Am. Soc. C.E., Assoc. Inst. C.E.

(Transactions of the American Society of Civil Engineers, vol. xxvi., 1892, p. 77.)

The points discussed are :

A. Live Loads.
B. Wind-Pressure.
C. Styles and Proportions of Bridges.
D. Intensities of Working-Stresses.
E. Combined Stresses.
F. Plate Girder Proportioning.
G. General Details of Construction.

The object of raising these points is to elicit the opinions of the other members of the Society, and, subsequently to advocate the issue of a uniform and simplified specification by the profession in place of those now in vogue in the United States, which are manifold and complicated.

The Paper occupies thirty-six pages, and the Discussion, in which forty-one members take part, one hundred and seventy-one pages of the Transactions.

A.—The Author describes the annoyance to competitors arising from the specification of concentrated wheel-loads for the calculation of strains, which he declares is needless, since the error in using equivalent uniform loads is very small. He reviews the tentative method for the treatment of concentrated loads, an exact mathematical formula,[1] and Professor Eddy's graphical method for the same purpose, as also Mr. T. Cooper's remarks in favour of the use of concentrated loads in his Paper, July 1889, and shows by means of Tables the amount of error to be only about 2 per cent. He offers to present to the Society the calculated equivalent uniform loads of the six most usual engine diagrams if his suggestion be adopted.

B.—The Author proposes that in accordance with modern specifications the assumed wind-pressure on an empty structure should vary between 40 lbs. per square foot for short spans and viaducts, and 25 lbs. for long spans; and on a loaded structure between 30 and 25 lbs. He gives his own method of calculating the superficial area exposed to wind-pressure, and calls attention to usual inaccuracies in the calculation of the stresses from wind-pressure in consequence of the omission of indirect effects, *e.g.* of the overturning moment.

C.—The Author recommends the plate-girder for spans up to 100 feet, the riveted single-system lattice (Warren) type up to 150 feet, the single-system panel (Pratt) type up to 250 feet, and beyond that span the single-system subdivided (Pettit) type with straight or inclined top-chords. He desires the system of bridge girders without overhead bracing ("pony truss") to be abolished.

[1] Transactions of the American Society of Civil Engineers, May 1890.

The distance between centres of trusses should not be less than one-nineteenth of the span, the depth should never exceed three times that distance. Great panel-length is a source of economy, but it should not be carried too far, and the depth of the eye-bars in the bottom chord should not be less than 2 inches in 15 feet to 10 inches in 40 feet. A system of floor construction is given, in which the metal stringers are 8 feet apart, with sleepers 12 inches by 8 inches, 13 inches between centres, and with guard timbers and angle-bars. Stiff bracing-bars in the lower lateral system are preferable to adjustable ties, and the latter should everywhere be avoided as much as possible.

D.—The Author discusses the subject of impact and of often repeated stresses as taken account of by the well-known Wöhler-Launhardt formula, and recommends its adoption. In respect of the formulas used for the calculation of long strutts the Author prefers that containing the simple proportion of length to radius of inertia to those containing the square of that proportion.

E.—The Author discusses the question of the permissible strain in members under stress from load and wind together, on the principle that the factor for wind may be higher than that for load. He refers especially to the bottom chords of bridge-trusses and to the inclined end-post of the Pratt truss, and enumerates several matters which have to be considered in the calculation of strains in the latter.

F.—The Author is in favour of extending the usual limit of the thickness of the web, viz., $\frac{3}{8}$ inch to $\frac{5}{16}$ inch in small plate girders, and also in favour of counting upon the web to resist bending, lowering, however, the factor for the strain per square inch now in use accordingly.

G.—The Author touches upon the following matters:—1. Objection to riveting the stringers to the cross-girders in long spans without a gap from end to end. 2. It is better to use end cross-girders, than to do without them according to former practice. 3. Desirability of making the axes of the various members at their junction to meet in one point, with the remark that to his knowledge that desideratum has never been attained for any structure yet built, but that he has now solved the problem. 4. The fault in fixing the end-diagonal of the lateral bracing to the pedestal, instead of the chord at its centre line. 5. The eccentric connections of adjusting bolts, by which the rivets in the angle-bar cleats are strained in tension. 6. The suspension of floor-beams by means of hangers. 7. The eccentric grouping of rivets, and other matters.

In the discussion much interest is shown in the question of the establishment of an uniform specification for railway bridges: A. Among forty-one contributors only four express no opinion, whereas a large majority of the rest approves either Mr. Waddell's plan of substituting a uniform load for the engine loads, or at least a uniform load with an additional load concentrated upon one, two, or four axles. As to the intensity of

the loads, opinions do not differ greatly. B. It is generally admitted that the intensity of the wind-pressure may be reduced from 50 lbs. for large-span bridges. Mr. Waddell's plan of calculating the exposed surface is not disapproved, and his remarks as to the usual incompleteness of strain-calculations from wind-pressure are agreed to. C. Opinions as to the limit of span for plate girders vary between 75 and 100 feet. There are several advocates of the multiple lattice girder, and of the bridge without overhead bracing for bridges up to 150 feet span, and for such over 150 feet all agree upon the large-panel Pratt truss with pin connections. Mr. Waddell's system of floor is considered good, only a few opinions being in favour of placing the rail-bearers vertically under the rails. D. On the question of impact of the live load some valuable contributions are made in the discussion, and the use of the Wöhler-Launhardt formula is recommended by most contributors, but more as a convenient way to expressing the action of the live load compared with the fixed, than as a safeguard against the effect of repeated stresses ("fatigue"), which, in their opinion, does not come into question in structures strained within the limit of elasticity. Opinions upon the intensity of the permissible stress differ but little. With regard to the formula for long columns, it appears that the majority would revert to the square of the proportion of length and radius of inertia as a factor in the formula. E. A factor for stresses from wind-pressure differing from that from the load is agreed to, few dissenting. F. Most writers agree to Mr. Waddell's recommendation to attribute to the web of a plate girder the function of transmitting bending-stresses, if proper regard is had to the weakening at its joints, but disagree to the use of any thickness less than $\frac{3}{8}$ inch. With regard to the distance apart of the stiffeners of the web, no very decided views are expressed. G. In respect of the various points under this class, there is general assent to Mr. Waddell's remarks, except in respect of the suspension of the cross-girders by means of hangers; these are only condemned if bolts are used instead of rivets.

M. A. E.

The Cantilever Highway Bridge at Cincinnati.

By Gustave Kaufman and F. C. Osborn, MM. Am. Soc. C.E.

(Transactions of the American Society of Civil Engineers, vol. xxvii., 1892, p. 173.)

This bridge, which was built across the Ohio during the years 1890 and 1891, has a total length of 2,966 feet, and carries a roadway 24 feet wide in the clear, with two side-walks each 7 feet in width, its main engineering feature being the central cantilever span of 520 feet from centre to centre of piers. The site was exceptionally favourable for economic construction, owing to the presence of a limestone ridge extending across the bed of the river

at a depth of only a few feet below low water; but the work was not carried out without experiencing great difficulties, which are described in the Paper.

The general plans had been approved by the Government in April, 1888; but for nearly two years the matter remained in abeyance, until the 31st March, 1890, when arrangements were made with the King Bridge Company to commence and complete the structure by the 1st January, 1891, under specifications to be prepared by the chief engineers of the bridge Company, whose appointment was made on the same date. Owing to the severe limitations of time, only twenty-four hours could be devoted to the preparation of the specifications, which included detailed provision for the foundation and construction of the abutments and of nine river-piers, containing together about 13,000 cubic yards of masonry, while the superstructure comprised 2,500 tons of iron and steel, in addition to the material of the flooring, paved roadways, and approaches.

The different portions of the work were sublet to separate contractors under heavy penalties for their completion within certain intervening dates. The river-piers, which were founded partly in cofferdams, and some in pneumatic caissons, and carried up to a height of 102 feet above low-water, were to be commenced not later than May 1st, and to be wholly completed by October 31st; while eight of them were to be in readiness for the superstructure one month earlier. By this time it was hoped that the finished material of the superstructure could be delivered on the site, Messrs. Carnegie, Phipps & Co., having undertaken to supply the iron and steel within sixty days from the placing of the order; and, finally, the contractors for the erection were to obtain possession of the finished piers and material on the dates above named, and to complete the structure by the 1st of January.

For a short time the programme was fairly well adhered to in all departments; but the Ohio is subject to floods, as well as the Licking River, which debouches into the Ohio close to the site of the bridge, where the variation between high- and low-water reaches an extreme rise of 69 feet. The year 1890 was marked by a succession of these floods, which left only about five weeks of low water during the fall of the year; and, although some of the piers were fairly started during this period, the operations at one pier were overtaken by the high water, which delayed further progress for a considerable time. Under the increasing difficulties the masonry contractors became demoralised, and it became evident that the completion of the work within the time was an impossibility. By the exertion of great energy, however, it was finally completed eight months after date, and opened in August, 1891.

In the design of the caissons, the piers, and the iron and steel superstructure, all the familiar features of American engineering are presented. The caissons are of timber construction, 58 feet in length by 22 feet in width. The piers are executed in first-class

masonry set in mortar composed of 1 part of cement to 2 of sand; and the actual cost of laying per cubic yard for labour, sand, and cement is given in the Paper as varying from $1·12 in the lower courses to $1·50 at the top of the pier.

The superstructure includes a cantilever span of 520 feet, with two counterbalancing or "anchorage" spans of 252 feet each, two independent polygonal trusses of 254 feet, and one of 162 feet, besides several smaller girder spans. All the larger trusses are of the "through" type, the footways being carried outside the main trusses on the projecting ends of the cross-girders, which pass through the posts of the main trusses, and are firmly riveted to them.

The tension members are formed throughout of eye-bars with pin connections; and in the upper chord of the anchorage spans the alternating-stresses are provided for by separate tension and compression members, proportioned respectively to the maximum tensile and compressive stresses. The maximum anchorage stress of 136,000 lbs. is taken by a steel eye-bar 6 inches by 1½ inch, passing 20 feet into the masonry, and attached to a box-girder 7 feet square and 2 feet deep. One or more samples of every size of eye-bar was tested for ultimate strength in the full-sized and finished bar, in addition to the usual tests for strength, elongation, and elastic limit of the material; and, with the exception of one faulty head, all the bars were found to break at the shank.

All members of the main trusses, except in the small spans, were of steel, whose prescribed limits of strength were from 62,000 to 70,000 lbs. per square inch, with an elastic limit of 36,000 lbs., an elongation of 22 per cent. in 8 inches, and a reduction of area of 40 per cent.

Full details of the calculated loads and prescribed working-stresses are given in the specifications appended to the Paper.

T. C. F.

On the Gauging of Running-Streams. By C. Ritter.

(Annales des Ponts et Chaussées, June 1892, p. 805.)

This Paper is chiefly occupied with the description of modifications introduced by the Author in apparatus for measuring the velocity of flow at any point in a stream, and with the methods of using such apparatus.

The principal instrument described is called by the Author a "hydrotachimeter." It is adapted for considerable depths, and has the advantage of not being liable to disturbance by solid matters transported in the water. It consists of two bells, side by side, filled with air, and submerged to any desired depth, to which are connected vertical tubes, each of which is bent over and passed into one leg of a U-shaped bend. This bend contains water, and when the air-pressure differs in the two bells, the column of water

will indicate the difference of pressure. Each bell carries a short horizontal tube projecting from it, one being open at the end, and the other having a small opening in its side, these tubes being of capillary size. If the tubes are parallel and the open end faces the direction of the stream, the difference of pressure at the two openings, and consequently in the two bells, is the pressure due to the velocity of the stream. There are three types of this instrument described—one adapted for moderate depths when the operator is near the surface of the water; another for surface velocities only, the operator being at some distance—as on a bridge; and a third for considerable depths, where the operator is at a distance. All the details of the construction and use of these types are minutely described. The third type is supplied with an additional gauge of the aneroid construction, which is connected with the tube under statical pressure, and registers the depth at which the observation is taken. It is also furnished with an air-pump, by which the necessity for large bells is avoided. A rudder is used to keep the instrument to the right direction.

A second part of the Paper describes other instruments as modified by the Author for use under special circumstances; viz., a small pocket gauge for use in small streams, which is a simplified form of the "hydrotachimeter," and an electric log, suitable for great depths, with a gauge to indicate the depth, and an electric bell to indicate when the bottom is touched.

A third section is devoted to auxiliary methods of gauging. When the velocity is very small, useful information may be obtained by noticing the ripples formed by dipping a needle vertically in the water. At a point where the velocity is just not sufficient to produce visible ripples, it is always 8 inches per second. Where two streams unite and the flow of one is known, that of the other may often be accurately obtained by simultaneous observations of temperature above and below the junction. If Q and Q' be the flow of the affluents, t and t' their temperatures, and θ the temperature of the united streams

$$\frac{Q}{Q'} = \frac{\theta - t'}{t - \theta}.$$

Similar information, but much less accurate, can be obtained by chemical analysis of affluents. The last section briefly treats of the calculation of flow from observations, and of the construction of diagrams of the régime of rivers.

A series of notes appended to the Paper discuss at more length points of detail in the matters treated of. The Paper is illustrated by two full-page plates and numerous engravings in the text. It is a continuation of previous communications on the same subject by the Author, published in the Annales des Ponts et Chaussées for June 1885 and December 1886, of which Abstracts appeared in the Minutes of Proceedings Inst. C.E., vol. lxxxii. p. 413, and vol. lxxxix. p. 507. C. F. F.

Notes on the Distribution of Nile Water and Maintenance of Works in the Basin Systems of Upper Egypt. Illustrated by 23 Maps of the Irrigation Canals, &c.[1]

By Lieut.-Colonel Justin C. Ross, C.M.G.,
Inspector-General of Irrigation.

This is a Report on the irrigation by the Nile of about 800,000 acres (721,548 *feddans*) of land in Upper Egypt, and may be regarded as a supplement to a previous Report,[2] which dealt chiefly with the cost of, and the results achieved by, the Nile irrigation of Lower and Middle Egypt (4,881,152 acres), extending from the Mediterranean as far as the commencement of the Ibrahimiyah Canal at Asyût, a distance of 395 kilometres (246 miles) from the mouth of the Nile. The works now described extend from this point to kilometre 861½, or a further distance of 290 miles up the river, and refer to the provinces of Girga, Kena, and Esna.

On each bank, east and west of the Nile, there are in this part of Egypt fifteen main canals heading from the river, and collectively delivering for irrigation at the rate of 63,299,000 cubic metres (2,235,520,780 cubic feet) of water per diem at "low Nile," or 98,471,637 cubic metres (3,477,722,800 cubic feet) at "mean Nile," of which approximately two-thirds are distributed in ninety-six basins on the west, or left bank, and one-third on the east, or right bank, in fifty-four basins. The dimensions of the canals vary considerably. On the west bank the average bed-width of eleven of the fifteen main canals is 54 feet, and their average rate of discharge at mean Nile, 2,817,500 cubic metres per diem. On the east bank the average bed-width of eleven canals is 44 feet 3 inches, and their average discharge at mean Nile, 2,702,560 cubic metres per diem. Of the remaining eight, seven are smaller canals; but the bed-width of the great Suhagiyah canal, the first that is met with after leaving Asyût, is no less than 80 metres (266 feet); it is about 70 miles long, and irrigates 122,630 acres, having a daily discharge at mean Nile of 30,000,000 cubic metres (6,600,000,000 gallons) of water. Besides the main canals, there are now also seventy interior reaches and branches of canals on the left bank, and sixty-one on the right bank, as aids to the effective distribution of the water. Some of these are also from 50 to 70 feet in width; and the average bed-width of the whole number is 30 feet. The efficiency of the irrigation depends upon the degree of success with which these masses of water are controlled, both when admitting it to the basins and when subsequently emptying them ("Sarf").

It is calculated that, allowing for evaporation, each feddan

[1] The original is in the Library of the Inst. C.E.
[2] Minutes of Proceedings Inst. C.E., vol. cvii. p. 466.

(1·109 English acre) should receive per diem at "low Nile" 100 cubic metres of water, and that the average depth delivered in the basins is a little under 1 metre (3·28 feet); but this is not sufficient for complete flooding, which requires one-quarter more in the forty days that the flood lasts. On account of the summer crops of sorgho and maize (Durah), most canals are not opened until August 15th, and the mean duration of the flood is from that date until September 24th.

Certain averages of the height of the Nile at Aswàn, based on records extending over about eighteen years, are taken to denote "low Nile," "mean Nile," and "high Nile." The people and the engineers all think in cubits,[1] and the height of "low Nile" is termed $13\frac{2}{24}$ cubits; "mean Nile" is assumed to be 1 metre above low Nile, and is called $15\frac{10}{24}$ cubits; and "high Nile" is $1\frac{1}{2}$ metre (5 feet) above low Nile, and called $16\frac{6}{24}$ cubits. By these terms an enormous difference is signified in the quantity of water coming down; and with a low Nile certain works have to be undertaken by the Nile watchers, such as shutting some of the regulators in a chain of basins, so as to store the water in the centre of a chain. It is necessary, therefore, that when, according to certain indications, a low Nile is foreseen, the Cairo authorities should give timely warning by telegraph to the chief civil authorities (the Mudirs) and the engineers in Upper Egypt; and the rule laid down for the future by the Inspector-General is that bad Nile should be declared if the height at Aswàn is below 13 cubits on the 15th, or below 14 cubits on the 22nd, or below 15 cubits on the 28th of August.

A large expenditure has been incurred with the view of making the whole of Upper Egypt practically independent of a low Nile, and to make each system, or series of canals and basins (as far as it is economically possible), enjoy the same advantages as the others. This applies especially to the prevention of *sharâgi*, a term which is used to indicate those lands which formerly were insufficiently, or not at all, irrigated by the fertilising mud (red water) brought down by the flood. One ancient custom was, for instance, first to fill the furthest and lowest basin of the system, or the lowest part of a basin, with red water, and, after the best part of the mud had there settled, gradually to dam the regulators in succession, and irrigate the upper land by the slow rise of shallow water. This has been remedied by circulating good red water during the whole of the Nile flood, and delivering it simultaneously to each of the basins at many points. Again, under the old system many of the distributing canals stopped short of large tracts of land cultivated with millet, and had no outlet to the basins beyond; on the new system these canals are arranged to carry a larger amount of water, which irrigates the millet lands (*nabâri*), even as far as their upper reaches, and is ultimately thrown off into the basin beyond through an opening

[1] A cubit, of 24 kirats, is 54 centimetres, or $21\frac{1}{4}$ English inches.

built in masonry in the bank by which the two cultures are separated. The spread of this nabâri (millet) cultivation is a most important point to be attended to, the more so that when the people have their nabâri well protected and well watered they sow sugar-cane in addition to sorghum.

In other places red-water canals which terminated in a basin have been carried through and beyond it, protecting both sides by banks so as to prevent any white or still water from the basin from mingling with the red water of the canal during its passage through it; and canals which ended suddenly on reaching a point where the Nile flowed against a rocky bank or gravel hill (*mahgar*), and seemed to bar their further passage, have been extended at considerable cost, so as to carry on the flow of red water into the succeeding basin system.

Siphons have also been constructed, by means of which the whole of the water in some canals is made to pass under other canals which, being at right angles to them, formerly barred their progress; and many canals heading from the Nile which carried an insufficiency of water have been deepened, so that they now ensure the delivery of the required 100 cubic metres of water per feddan throughout the basins which they fill.

These new works and innumerable distributing canals and regulators have been built during the last few years, and have very greatly improved the irrigation and increased the extent of richly-cultivated land; but a few large works in each basin-system remain to be built, principally in the provinces of Girgâ and South Asyût.

In carrying out these ameliorations, the works in masonry which have been constructed since the British occupation (chiefly since 1886) far outnumber those which previously existed, as shown by the following comparative Table:—

—	Old Works.	New Works.	Total.
Regulators	71	84	155
Culverts	19	50	69
Heads	17	50	67
Escapes	17	37	54
Siphons	25	19	44
Road bridges	5	3	8
Foot bridges	2	5	7
Inlets	..	3	3
Aqueducts	2	..	2
Total	158	251	409

The "regulators" and the "escapes" are bridges of from one to five (generally three) arches, each of from 6 feet 8 inches to 10 feet span. They are roughly classed as bridges with 5, 4½, or 4 metres (16 feet 8 inches, 15 feet, or 13 feet 4 inches) depth of water on the up-stream side of the regulating apparatus, and in

their normal condition have 1 metre less depth of water on the down-stream side. The arches are closed by planks one above another, each of which is 10 inches in height; and, according as one or more of these are removed, water in more or less quantity passes through the bridge. Taking, for example, the 4½ metres (15 feet) water-depth as a standard, and allowing 2,000,000 cubic metres per arch to be the maximum that is to be permitted to pass into or from the canal or basin in twenty-four hours, the Report contains Tables showing that when there are four 10-inch planks resting in the grooves on the floor of the bridge the discharge per arch is 1,982,500 cubic metres per diem, which is near enough to the 2,000,000 cubic metres, allowing for leakage and bad placing of the planks in the grooves. In the 5-metre water-depth six planks should be in, and in the 4-metre depth two planks.

If the "*ghafirs*" (Nile watchers) were always skilful and steady, the manipulation of this machinery would ensure a regular supply of water; but often these *ghafirs* get panic-stricken when they see the water rising rapidly, and begin hauling out the planks, without stopping to take an equal number out of each arch, until, owing to the rush of water, they can get no more. This causes violent waves, which undermine the slopes of the canal, displace the protecting pitching, and create lateral eddies, with other bad effects, all of which do much damage to the works.

Even with the remodelled system there is a very large width of land immediately bordering on the Nile which the people habitually irrigate by low-lift shadoofs. This irrigation is not maintained by the Government, as the people, more especially in the provinces of Kena and South Girgà, have occupied it by villages. They maintain short canals running down the tract, which, however, are at so high a level that they run absolutely dry when the Nile sinks below 14 cubits. The same system of shadoofs is employed on the edges of all the great canals, the first 9 or 10 miles of the great Shanhuriyah canal being closely cultivated throughout by people who live in hamlets built on the spoil-bank, and who cultivate for several hundred metres from the main canal by private watercourse. So, also, whenever the desert borders on the Nile or on a canal, the people almost always lift water on to the bordering strips of land. When, however, the Nile fails to rise sufficiently, these people get no water, and are much inconvenienced. The Report recommends that they should be assisted by the Government, and that they should be supplied with Archimedean screws (called in Arabic "*Barimah*") to replace their shadoofs, it having been found in the Delta that these screws lift higher and give a much larger duty than any other machine. The Government might also supply these people with maize seed when, by reason of the struggle for irrigation, they have been unable to sow their usual crops before September 1st. Maize gives a very good return in sixty days, whereas the sorghum requires at least from one hundred to one

hundred and ten. Latterly half the rent on these lands has had to be remitted; but by a little judicious help in these two matters the irrigation in years of low Nile would be much facilitated, and full rents would be secured.

The canals and basins are divided into fourteen series, or "systems," each of which is separately described and minutely dealt with in the Report under nineteen headings. These include accounts of the former state of the canals and works in each system, the improvements that have been introduced, the banks, borrow-pits, auxiliary red-water feeders, positions and state of the bench marks, masonry works and works remaining to be done, with detailed instructions how the Nile water is to be dealt with and distributed at low Nile, mean Nile and high Nile, on its admission and on its discharge from the basins, and other particulars. A brief enumeration of the canals and basins forming one of these systems may serve to indicate some of the many complicated questions which are involved in the equal distribution of the Nile flood-water.

The Sâhil Farshut System comprises nineteen basins, 119,838 acres in extent, which are irrigated by the following canals:—

1. The Tûkh-Der Canal, 26 miles in length and 30 feet wide, was formed in 1889–91 out of two smaller canals. It takes its water from the Nile at kilometre 692, irrigates two basins, and formerly, after discharging into the second, went no further; but recently a channel has been cut through the gravel bank of the Nile which carries it 6 miles beyond this basin, where its escaping waters now feed the Marâshdah Canal.

2. The Marâshdah Canal fills three basins, 11,075 acres in extent, and, after traversing them, has an efficient escape at Haw up an old canal into the Nile.

3. The Rannân Canal takes its water from the Nile at kilometre 635, follows the edge of the desert for 16 miles without irrigating until it has passed Haw, and then divides its waters among several small canals and two large distributing canals, the Qammânah with several branches, which ultimately discharges into the Dahasah basin (9,776 acres), and the Samâsmah, which ultimately discharges into and increases the water of the Damraniyah, another very large canal which takes its water direct from the Nile at kilometre 597.

4. The Damrâniyah Canal supplies water to three large distributing canals, all taking from one head and filling several smaller branches which spread in several directions and supply several basins. Subsequently at the town of Farshut, the main canal divides into two and fills the exceptionally large basin, Nabâri Sâhil Farshut, 42,000 acres in extent.

5. The Rashwâniyah Canal is a large new canal which irrigates the upper part of the South Suhag System, and also supplies red flood-water to the large Samhûd Basin (25,365 acres).

The tract of land between the Rashwâniyah Canal and the Nile is irrigated by a distributing canal called Sâhil Bakhânis which

passes under the Rashwâniyah Canal by a siphon, and then under three other canals in the same way and ends in a basin on the Nile bank. It has a number of small branches.

The whole of the Sâhil Farshut System is pre-eminently distinguished for the extent of its millet (nabâri) and sugar cultivation. For many hundred years there has been sugar cultivation near Farshut, and it is now on the increase. There are many native mills in the villages which make a coarse syrup and export it, as well as a coarse brown sugar.

O. C. D. R.

Electric Block-Setting Machinery at the Bilbao Harbour Works.

By James Grosclaude.

(Le Génie Civil, vol. xxi., 1892, p. 241.)

Extensive improvements are in progress at the port of Bilbao, in Spain, among which one of the principal works is a breakwater 1,600 yards in length. The breakwater is formed of:—

(1) A base of loose stone rising to nearly 20 feet below low water, having a width of 177 feet on top, and a maximum height of nearly 50 feet.

(2) A mass of concrete blocks deposited at random on the rubble and rising to low-water of equinoctial springs with a surface width of nearly 100 feet.

(3) Concrete blocks with an interior dumpling of concrete in bulk, forming a wall 23 feet in height, 40 feet wide at the base, and 33 feet 6 inches on top, resting on the random blocks, which are filled in with concrete to form a level bed.

The machinery here described is used for moving the blocks in the intermediate part of the breakwater from their place of manufacture and depositing them under water. The blocks are of two sizes, respectively 1,060 and 1,766 cubic feet in contents, the larger blocks being laid on the outside face of the work. The yard in which the blocks are moulded is traversed by rails of 18·7 feet gauge, on which travels an electric crane adapted to lift a block and transport it to the truck by which it is carried to a pier for shipment. The crane is 8-wheeled, one pair only being driving-wheels. The electric current is received from an overhead conductor on the "trolly" system. The dynamo-motor makes 600 revolutions per minute, and the main shaft can be made to drive either the pumps of the hydraulic presses for lifting blocks or a second shaft coupled to the driving-axle by chain-gearing. The stroke of the hydraulic cylinders is $15\frac{3}{4}$ inches. The speed of travel of the crane is 33 feet per minute.

The crane runs on to the platform of the truck above mentioned, the permanent way for the latter being set below the level of the yard, and deposits the block. The truck runs on four rails,

and its motor receives the electric current from bare copper-wires laid along the retaining wall of the cutting in which the truck travels. The block is thus conveyed alongside a jetty where there is a second travelling-crane by which the block is lifted, traversed along the jetty, and is then lowered into the barge by which it is conveyed to its place in the breakwater. The travelling-crane on the jetty is similar to that in the block-yard, except that its hydraulic cylinders have a stroke of 23 feet. Each barge carries two blocks.

C. F. F.

The Port of Genoa.

(Giornale del Genio Civile, 1892, pp. 287, 352.)

The recently published official report on the progress of the works for the improvement and enlargement of the port of Genoa gives full details of the construction of the piers, quays, and warehouses, the extension of the railway connections and other incidental works which have been undertaken since the time of the Galliera Convention, under which the first funds for the purpose were provided. The works in and about the port are not yet completed; but in all essentials the water area is now fully available.

Dealing firstly with the "external works," *i.e.* the enlargement and enclosure of the port, the western pier (Molo di Ferrari Galliera), which forms an extension of the former "New Pier," has been carried seawards in a southerly direction for a distance of 2,155 feet, into a depth of from 50 to 80 feet of water, then bending south-east for a further length of 2,763 feet into a general depth of about 100 feet. The normal width at mean water-level is 115 feet 6 inches, increased to 131 feet 3 inches at the pier head. The (1) base of the pier, up to a depth of 20 feet below the surface, is formed of random blocks to an external slope of 2 to 1, and internal slope 1½ to 1. Upon this (2) the structure is composed of artificial blocks to 14 feet 9 inches above water-level; (3) the quay (33 feet 2 inches in width) and outer parapet-wall rising on this, the coping being at 32 feet 9 inches above the water. The construction of this and of the eastern pier, or Molo Giano, which runs out from the shore in a south-westerly direction for a length of 1,952 feet, and has a width of 74 feet 8 inches at water-level, was carried out in three distinct periods, and was marked by some special features.

In the first period the object was to construct as quickly as possible an effective breakwater. The nucleus of the base was therefore formed of small stones, up to 1 cwt., let down in boxes with hinged bottoms; while simultaneously the internal and external slopes were formed with larger stones, shot off a closed deck-pontoon, and in some cases specially lowered. On the inner

face the weight of the stones ranged from 2 to 10 tons; on the outer face from 5 to 50 tons; though some were between 80 and 100 tons, and one weighed 137 tons. The assortment according to weight enabled the base to be constructed with greater solidity and compactness, and effected a decided economy. The average rate of work was 608 tons per diem of small stones, and 880 of large; total, 1,488 tons, the maximum daily quantity being 2,330 tons.

Upon the completion of this portion of the work, it was left to consolidate for a period of from one to two years, during which time the artificial blocks were prepared. The normal dimensions of these blocks were 13 feet 1½ inch by 6 feet 7 inches by 5 feet 9 inches, the top course being 16 feet 5 inches by 6 feet 7 inches by 5 feet 9 inches. These were placed in regular courses, with only the smallest interstices, so that the water has no disintegrating action inside the mass, and are laid as "headers," *i.e.*, exposing the small end to the water. In the lowest course the average time required for laying one block was one hour twenty minutes; in the other courses forty-five minutes. This second period being completed, the foundations of the quay walls were put in and allowed to consolidate for some months before completing the wall, the nucleus being brought up to the same level.

Owing to the precautions taken, the final settlement of the structure nowhere exceeded 2 feet 8 inches, and no fracture or fissure was produced. In a total cost of upwards of £700,000, the damage or loss caused by the sea during the progress of the works was only £564. The following materials were used:—

—	Western Pier.	Eastern Pier.
	Tons.	Tons.
1. Base (random blocks)	4,439,097	500,784
2. Artificial blocks	153,861	31,725
3. Quay wall, and upper portion . .	95,296	10,527

Total cost, western pier, £626,740; eastern pier, £79,880.

Average cost:—

Random stone in base	2*s.* 2½*d.* per ton.
Artificial blocks	17*s.* per cubic yard.
Entire structure, western pier	£390 per lineal yard.
„ „ eastern „	£126 „ „ „

These two piers enclose the outer harbour or roadstead, and afford an entrance 2,133 feet in width to the port. The "internal works" carried out comprise firstly the construction of quays and jetties, and the dredging and excavation of the harbour basin. The minimum depth in the harbour is now 28 feet, while over most of the area the depth is 29 feet 6 inches. The greater portion of the material removed was of medium consistency or soft bottom, which was taken by each dredger at the rate of from 80 to 100 cubic yards per hour; while in harder ground the limit was

15 to 20 cubic yards. The quay walls, which are constructed mostly of artificial blocks (concrete), are, in the portions built since 1888, provided with a subway for hydraulic mains, electric cables, &c. The cranes and shears are of various types—hand, steam, and hydraulic; fixed, travelling, and pontoon—and range in power from 30 cwt., of which there are twelve hand-power and forty-four hydraulic, to 120 tons. The goods sheds on the several jetties are of four types: (1) Enclosed buildings containing loading-bank 3 feet 6 inches above rail-level. Total area of this type, 5,760 square yards; (2) Open sheds containing horizontal loading-bank. Area covered by this type, 12,000 square yards. Most of these sheds have been enclosed by sliding shutters; (3) Open sheds with inclined loading-bank. Area covered, 25,200 square yards; (4) Open sheds without loading-bank. Area, 4,800 square yards.

In the construction of the harbour-works, the sandstone for ashlar masonry was obtained from the Monterosso quarries at Spezia, and granite from Baveno, on Lake Maggiore; stone for rubble masonry and for breaking for concrete from the Chiappella and S. Lazzaro quarries; puzzolana from S. Paolo, at Rome, and from Bacoli, near Naples; and lime from Sestri-Levante.

Amongst the auxiliary works were the extension and connection of the railway systems, involving heavy tunnels, and the laying down of several miles of sidings on the quays; the construction of a main intercepting-sewer to discharge beyond the limits of the port: and the electric-lighting of the quays and buildings. In addition to the government works, the municipality has erected isolated stores for petroleum and other inflammable substances, and has reconstructed on a greatly enlarged scale the dock and warehouses adjoining the old port; while the Chamber of Commerce has also built a large block of warehouses near the eastern pier. Several streets have been re-aligned, and new communications established, and large buildings erected in connection with the Customs and the passenger-service.

The total expenditure up to the date of issue of the report is as follows:—

	£.
Maritime works (piers and quays)	1,316,503
Excavation and dredging, buildings, lighting, cranes, sewer, &c.	736,122
Railway works	435,600
	2,488,225

	Lineal yards.
Length of quays and jetties available for large vessels	8,580
,, ,, ,, small ,,	1,094
,, ,, ,, mooring off	1,783

		Square yards.
Area of quays available for storage of merchandise	covered	55,224
	open	207,252
Total area of quays, including sidings		669,528

P. W. B.

The Harbour Works at Leixões, Portugal.

By A. J. N. Soares.

(Revista de Obras Publicas e Minas, 1892, p. 67.)

The Author is director of the harbour works at Leixões, near Oporto, and the description of which the following is an abstract deals with the work carried out in the financial year 1890–1891, and refers to future improvements to be made in 1891–1892. The whole work should be completed in 1892, and the Author discusses the best means of improving the port and connecting it to the river Douro and the city of Oporto. In 1889–90, the work at the heads of the two breakwaters had been advanced by the use of caissons; but the contractors found great difficulty with the caisson system owing to local conditions.

The position originally laid down for the heads was found impracticable, and it was changed about 9 yards, the width of the entrance being still kept the same. Permission was also obtained to use the system of artificial blocks for the northern breakwater. The caisson for the head of the northern pier was ready in September, 1889; but it was only placed in position in July, 1890. The removal from this site took place on September 2, 1891, and a week later the caisson was brought into position at the head of the southern breakwater. A bed of concrete 5·6 feet thick was then laid inside it, and above this 6·5 feet of dry masonry, after which the whole was built up solid to 20·7 feet below datum. Unfortunately there was a very rough sea, and as no water had been let into the caisson, the high tide loosened the block from its foundations, and rendered it useless; 7,060 cubic feet of concrete and masonry had to be removed, causing great delay. By the 25th October, the caisson was floated to a sheltered position in the harbour, and remained there until 11th July, 1891, when it was again brought into its proper position. The Author is satisfied that the conditions are similar to those at Colombo, and that the caisson system is not suitable.

This method was, therefore, abandoned for the north pier, where it was necessary to put down cement to a depth of 22 feet, and blocks of concrete took the place of the solid bed previously used, and these blocks were embedded in the masonry after the caisson had been pumped dry.

The width of the entrance to the port is 240 yards, and firm ground was usually found at a depth of 9·8 feet below the bottom of the sand, and at 60 feet below datum. The foundations of the north pier consist of concrete in bags. The Author then gives details of the number and sizes of the large concrete blocks used. The rest of the work done in the past year has been the construction of the breakwaters up to the heads, of which 73 feet was built in the north pier, and 51 feet in the south pier; but little damage has been done by the sea. Diagrams are referred to which show the amount of building completed each month, but these do

not appear in the original. The quantities are, however, given under different headings, and it appears that the total amount of masonry constructed was 105,277 cubic feet, and of other work of various kinds 1,840,000 cubic feet. A large number of concrete blocks have also been prepared to protect the breakwaters.

The stone was brought from St. Gens, during one hundred and sixty-two days of the year, the average per day being 3·01 trains, each consisting of eleven wagons. The total amount paid to the contractors during the year was £46,239, of which £43,920 was for works on the port itself, and £2,319 on the auxiliary works. The total outlay for the whole eight years during which the work has been in progress is £874,276, of which £710,607 has been actually expended on the work at the port, and the remaining £163,669 in auxiliary works. In this total, the sum of £41,722, upon which interest at 10 per cent. per annum has to be paid, is not included.

The Author proposed, in 1888, that quays should be constructed on the south pier, which proposal had originally been made by Sir John Coode in 1881, and the Author also considered it advisable to limit the width of the entrance to 218 yards; but after a committee of consultation had been nominated by the King of Portugal, it was decided to retain the width of 240 yards, although Sir John Coode originally advised a width of 196 yards. The Author, however, fears that the water inside the harbour will be often too rough to allow vessels to come alongside the piers, and he believes it will be advisable to construct an inner port or docks, so that vessels may load and unload in any state of the weather.

He then considers the question of a canal from Leixões to the Douro, and is of opinion that one of sufficient width for barges would serve the purpose, as a real ship-canal would be too expensive. The number of vessels which entered Leixões during last year was little over one thousand, and the total tonnage coming in and going out was under 700,000 tons. The imports were 372,657 tons, of which 330,815 tons were in sea-going bottoms, and 41,842 tons in coasting boats. The exports, including wine, were only 82,646 tons, of which 62,341 tons were in sea-going bottoms, and 20,305 tons in coasters.

The maximum tonnage of ships entering Leixões is 1,200, and it appears that steamers which are too large to pass the bar at the mouth of the Douro could be filled at Leixões by coasters from Oporto.

The harbour is already used as a refuge, and is the only place of safety northwards from Lisbon. In reply to criticisms, the Author states that the accident to the corvette "Bartholomeu Dias" and the wreck of a yacht in the harbour were due to the incomplete state of the breakwaters. He believes that a railway to join that of the custom-house branch at Oporto would serve all present needs, and considers that buoys for attachment should be placed in the harbour, a light-house built at the end of each pier, and dredging begun. E. R. D.

The New Lock at Ymuiden and the Bulkhead Dam at Schellingwoude. By R. O. van Manen.

The New Pumping-Engines at Schellingwoude. By L. T. Eijmer.

(Tijdschrift van het Koninklijk Instituut van Ingenieurs, 1892–93, p. 13 *et seq.*)

In 1889 it was decided to deepen the navigation-canal between the North Sea at Ymuiden and Amsterdam, and to lower its bottom to 30 feet below mean sea-level. The existing locks at Ymuiden had become too small for the large ships built of late years. A new lock is now being added to the old ones, which will allow the passage of ships of 650 feet in length, 60 feet in width, and drawing 28 feet 4 inches.

The dam closing the eastern entrance to the Y roadstead before Amsterdam, and separating it from the Zuyder Zee, constructed with the object of maintaining a constant water-level in the North Sea canal, caused the fairway of Pampas east of this dam to silt up at an exceedingly disquieting rate.

As dredging between the locks in this dam at Schellingwoude and the deeper water to the east was of no avail, the channel silting up again during every gale, a dam is now being laid from the original bulkhead dam, at a spot south of the locks, in a more or less easterly direction, and parallel to the fairway between the lock and the open sea. This channel is to be kept to a depth of 9 feet below low water-level over a width of 750 feet. It lies south of the mainland, and north of the new leading dam. The sea-bottom here is very soft, composed of silt, bog, fine sand and clay mixed, and only at a depth of 15 to 20 feet below the bottom the usual formation of harder sand is met with, which, however, is not found pure till a depth of 50 to 60 feet below mean sea-level is reached. The core of the dam was dumped up with sand, which settled regularly, except at the spot where the direction of the dam crossed a deep gully, recently silted up, where the sand went down to a depth of 66 feet below mean sea-level, forcing its way through, and displacing the soft layers of silt. The top of the dam reaches to 4 feet above mean sea-level, where it is 42 feet wide, and is covered with a layer of puddled clay and a top of rubble stone. The side slopes are formed of fascine mattrasses 2 feet 6 inches thick, covered with stone rubble 1 foot thick.

The existing pumping-engines at Schellingwoude, intended to maintain a constant water-level on the Y roadstead and North Sea Canal, consist of three horizontal turbines, driven each by a 200-HP. engine. Experience proved that this arrangement was insufficient for the work it had to do, as occasionally 6,000,000 tons of water have to be displaced daily.

Additional power will be provided, and the new pumping-engines will consist of six scoop wheels, 28 feet 4 inches diameter, 10 feet broad, with centres at 8 feet above mean sea-level. They are calculated to develop 300 water-HP. with a lift of 22 inches. The whole will be placed on a pile-foundation, for which a sand-mound has already been deposited in the Y on the inner or western side of the bulkhead dam at Schellingwoude.

The two Papers are illustrated.

H. S.

The Original Projects for the New Lock at Ymuiden.

By A. A. Bekaar.

The Construction of the New Lock at Ymuiden.

By W. K. du Croix.

(Tijdschrift van het Koninklijk Instituut van Ingenieurs, 1892–93, p. 18 *et seq.*)

The rapidly increasing dimensions of ocean-going steamers necessitated larger dimensions for the North Sea canal and locks to enable the newer class of vessels entering the port of Amsterdam. In the project of 1887 the length of the new lock to be constructed at Ymuiden was fixed, between doors, at 683 feet 4 inches, its width in the clear at 84 feet 4 inches, and the depth over the sills at 28 feet 4 inches under Amsterdam Peil, or mean sea-level. In getting out the details for this work it became apparent that a greater depth over the sills would be desirable, and in the project of Engineer C. de Bruin the outer or seaward sill was proposed to be placed at 30 feet under Amsterdam Peil, and the two inner sills at 31 feet below Amsterdam Peil. The length in the clear between gates of the lock-chamber was also increased to 750 feet. In 1889 again it was decided to increase the depth over sills at mean sea-level to 33 feet 4 inches, or 31 feet 8 inches below canal surface-level, so that ships of 750 feet length over all of 80 feet width, and drawing 31 feet, should be able to pass through, leaving a space of 8 inches between its bottom and the inside sills. The "Campania" of the Cunard line and the new steamers to be built for the White Star line would therefore be able to enter the canal.

Engineer Blom in his first plans had adopted the system of concrete foundations put down in the simplest way, but during subsequent examination of the site by borings so much water was met with in the sandy soil, bursting forth with such strength and in such volume that excavation in the dry of the foundation-pit was considered to entail too great a risk, if not proving impossible. Plans were therefore prepared for an execution by means of pneumatic caissons. According to these plans each bay, containing a

pair of gates and their sills, were to be founded on five caissons and the walls of the lock-chamber to be built up inside of iron boxes up to 11 feet below Amsterdam Peil, to which level it was considered that the ground-water in the pit could be kept down by pumping during construction. The walls and floor of the lock-chamber below this level were to be built with concrete blocks set by divers.

While actually excavating the pit it was, however, found that a much smaller volume of water had to be contended with than was expected, the idea of employing pneumatic caissons was abandoned, and the excavation proceeded in the dry to a depth of 25 feet below Amsterdam Peil, with a deeper channel on the north side of 34 feet below Amsterdam Peil, the pumps keeping easily abreast of the infiltration.

The ground-borings made in 1887 on the site of the proposed lock showed the soil to consist of sea-sand and shells to a depth of 56 feet 8 inches below Amsterdam Peil, or mean sea-level, below which a thick layer of clay and a thin layer of peat were found, both very hard and compact. The foundation-pit, 1,000 feet long and about 233 feet wide, was excavated by means of two steam navvies, for the greater part to a depth of 25 feet below Amsterdam Peil, with a deeper trench along the north side to 30 feet to 34 feet below Amsterdam Peil. In this trench a ground-spring broke out on the 17th of August, 1890, in which a depth was sounded to 60 feet below Amsterdam Peil. This spring sanded up again the year after, but it caused the excavation in the dry to be stopped. The further deepening was carried on by sand-pumps and bucket-dredgers, while the water-level was kept down to 30 feet below Amsterdam Peil. The foundation-slabs consist of two layers of concrete superposed, each 4 feet 2 inches thick, and dumped through shoots following each other as closely as possible. These slabs for the lock-bays were dumped from floating stages, those for the foundation of the lock-chamber walls from side stages. The whole mass of concrete was deposited in four months, working day and night. The average daily quantity put down was 530 cubic yards, the total mass amounting to 34,000 cubic yards. During the winter of 1891–92 the concrete was left to harden, and did so satisfactorily under a covering of sand 6 feet 8 inches thick. The following spring the concrete on the top which had not sufficiently hardened, or where cracks appeared, was cut away to a depth of from 4 inches to 8 inches, and the whole levelled with concrete of a harder nature. The heavy slabs are surrounded by a sheet piling, 4 inches to 8 inches thick, driven down by water-pressure to a depth of 53·4 inches below Amsterdam Peil.

The ground-springs, which were met with during construction, were caused by the previous trial-borings, as they occurred in the same spots where the boreholes had been. They brought up fresh water and marsh-gas, evidently from underneath the layer of compressed peat, at a depth of 60 feet under Amsterdam Peil.

These springs were isolated and covered by iron funnels leading to cast-iron pipes, by which the water was removed without retarding the work or causing interruption. After completion of the work these pipes and funnels will be stopped up and filled in with concrete. The concrete is principally made of Andernach trass.

A diagram showing the groundwell funnels is added to the second Paper.

H. S.

Telescopic Hydraulic Lift at Marseilles Docks.

By J. Donaudy.

(Bulletin de la Société Scientifique Industrielle de Marseille, 1892, p. 7, 4 Figs.)

This lift was erected in November, 1891, in the staircase-well of the Dock Company's offices (Hôtel de la Direction des Docks). It was designed by Mr. Samain, of Paris, on his patent telescopic system. The telescopic principle was adopted for the lift-rams, because the nature of the ground below the building made it impossible to employ a cylinder of the length necessary for an ordinary direct-acting lift. The weight of the lift-rams and cage is approximately neutralized by a vertical hydraulic balance, the pressure on the piston of which is produced by weights.

To the upper side of the balance-piston is connected a concentric cylinder of smaller diameter, sliding over a fixed piston. From the action of the water from the high-pressure mains—used to supply the hydraulic machinery in the docks—on the lower end of this cylinder the motive power for raising the lift is derived. The total pressure need only be that necessary to overcome the unbalanced load and the friction. As the cage ascends the column of water, under the telescopic rams, rises, and an increasing load has to be balanced. In order to adjust the pressure on the balance-piston to the varying load a device has been adopted which constitutes the special feature of the machine. The balance-weights are connected by radius bars or links to the exterior of the motive-power cylinder—which also forms a piston-rod to the balance piston—and the vertical motion of the weights is retarded or accelerated, relatively to that of the piston, by means of fixed curved guides on either side of the balance-cylinder, which act like cams. Thus the pressure exerted by the weights on the piston varies according to the extent to which they are horizontally deflected by the guides.

The hydraulic balance-cylinder has a diameter of 16·14 inches, and a length of 8 feet 10·3 inches. The diameter of the motive-power cylinder is 4·91 inches. Above the balance-piston, on the area not occupied by the motive-power cylinder, atmospheric pressure is maintained; the exhaust pressure from the motive-

power cylinder is, however, about 2 atmospheres, as the water is returned to the tanks at a certain elevation. The pressure of the water from the mains is about 739 lbs. per square inch, while that in the balance-cylinder does not exceed about 90 lbs. per square inch. The total lift is 68 feet 10·78 inches.

There are four telescopic rams, all working within each other, and into a fixed cylinder of 6·06 inches diameter, sunk in the ground. The smallest ram has a diameter of 4·4 inches.

In order to avoid shocks during the ascent, at the moment when each ram reaches the end of its stroke, the water enclosed in the annular clearance space between the ram in question and that in which it slides is throttled at the proper moment, instead of being allowed to pass freely from the annular space to the interior of the ascending ram. An arrangement is provided to compensate automatically for the leakage thus caused. During the descent shocks are prevented by means of a kind of dash-pot, which comes into operation as each ram approaches the lower end of its stroke. These devices have not proved quite successful in practice, as—without being at all dangerous—shocks are still perceptible.

In addition to the usual guides for the cage, the second of the telescopic rams carries a crosshead by which the telescopic column is also guided about the middle of its height. This has, however, been found superfluous, as the column tends naturally to maintain itself in a perpendicular position, provided the lower end of the hydraulic lift-cylinder is not rigidly fixed.

The distribution of water to the lift is controlled by a piston-valve actuated in the usual way. The cage can be automatically stopped at any floor by means of projecting pieces acting on the valve-rod. As a rule the whole lift—of 68 feet 10·78 inches—with three persons in the cage, is effected in rather less than two minutes; the descent is somewhat more rapid. The quantity of water used for one complete lift is about 1·059 cubic foot.

The Author discusses the question of safety, and arrives at the conclusion that a practically impossible combination of breakages in different parts of the machine would be required to produce a serious accident.

G. R. B.

The Water-Power Works of Wynau, Switzerland.

(Glaser's Annalen für Gewerbe und Bauwesen, September, 1892, p. 92.)

An account is given of the utilization of the water-power of the River Aare at Wynau and the surrounding district within a circuit of 12 miles. The power is distributed partly by electricity, and partly by means of compressed air. Though the Aare is capable of yielding a far greater amount of power, it was ascertained that the needs of the locality were only about 1,600 HP., and the works were therefore laid out for 2,000 HP. at the turbines. If

it had been only necessary to supply power within a radius of from 3 to 4 miles, there is no doubt that compressed air alone would have been relied upon, as this system is less costly than electricity in the matter of distribution; but the distance was in some cases prohibitive for the former plan. The economy secured in the cost of copper by the employment of currents of high voltage, and the importance of increasing the insulation by means of oil-vessels was studied in designing the works. The electricity is in all cases conveyed by overhead wires, which vary from 3 to 6 millimetres in diameter, in accordance with the strength of the current. The voltage is reduced by means of transformers from 8,000 volts to from 100 to 150 volts at the places where the power is employed; and in this vicinity the cables are laid underground for a short distance, and insulation is carefully attended to.

The pneumatic distribution of power takes place from the central station at Wynau, where the air is compressed to eight atmospheres, and is from thence conveyed in mains to the points where it is required. Five air-compressors will be driven by the turbines, capable of compressing 2,500 cubic metres of air per hour. The two mains will be: the one, 250 millimetres, and the other 175 millimetres (9·84 inches, and 6·89 inches) in diameter. Smooth cast-iron pipes will be employed, made without flanges, and coupled together by external collars and india-rubber rings. The house-connections will be carried out with lead piping. The advantages claimed for this latter system are the absolute freedom from danger, the small space needed for the motor, and the ease with which power can be supplied over a wide area. Tables are given of the cost of electrical power for mechanical purposes, and for illumination, and also for the use of compressed air in various ways.

G. R. R.

The Comparison of River-Pollution.

By Prof. R. Baumeister.

(Deutsche Vierteljahrsschrift für öffentliche Gesundheitspflege, 1892, p. 467.)

It is pointed out by the Author that though the degree of river-pollution may be indicated by means of chemical analysis, there is no method by which it is possible to set forth all the various factors which may influence the prevailing conditions in respect to any stream when it becomes necessary to compare one place with another. Something in the nature of a mathematical formula would therefore appear to be desirable for this purpose. The processes relied upon for the removal of pollutions caused by sewage are notably either copious dilution, or gradual self-purification. For the former ample volume suffices; for the latter, rapidity of flow in the river is also an essential. The minor elements are likewise noticed, among which are the

presence of algæ, the existence of rapids or weirs, the chemical effect of rocks in the river-bed, and of certain kinds of trade-refuse; but as these latter matters are of purely local significance, they may here be omitted. The extent to which sewage must be diluted in order to render it harmless when discharged into a stream of given volume at dead low-water can readily be fixed by a proportion; and von Pettenkofer has laid down the rule that no harm can arise when the volume of the sewer-water is not more than one-fifteenth that of the river into which it passes. But this simple statement should, according to the Author, be based upon the amount of impurities present in the sewage. This latter factor may remain constant, while the volume itself depends to some extent upon the weather, and upon the daily consumption of water. When the water-supply reaches 150 litres per head per day, the dry weather flow of sewage will be twice as great as when that supply is only 75 litres per head. The purifying power of the river does not change in the same proportions, and it would be better to set down the population contributing to the sewers as the figure to be taken into account when calculating the pollution.

Leaving out of consideration the mineral matters in suspension in the sewage, the Author takes the suspended organic matters, and all substances in solution as pollutions, and from numerous analyses he assumes 190 grams per head per diem, as representing the average amount of impurities discharged from water-carriage towns. The total pollution, however, varies widely, in accordance with the manner in which the excreta are dealt with; but even in towns worked wholly on the dry system, the dejections of a certain proportion of the inhabitants reach the river. Taking the proportion of the inhabitants whose excreta pass direct into the sewers as c, and indicating all other impurities by 1, the expression $(1+c)$ will represent in a definite form the whole amount of impurities conveyed into the river. In a town entirely on the dry system, $c=0$. If half the population used water-closets, $c=0\cdot5$, and if the town was entirely dealt with on the water-carriage system, $c=1$. With regard to the rapidity of the flow in the stream, it must at any rate suffice to carry away the sewage, and according to von Pettenkofer, it should, at least, be equal to the velocity of flow in the sewer, or not less than $0\cdot6$ metre per second. Without attempting to lay down any standards, it is pointed out that from the foregoing factors a simple equation may be framed which may be described as the "coefficient of pollution":—

$$\frac{Q\,v}{E\,(1+c)}.$$

Here Q equals the daily flow in cubic metres, when the river is at its lowest level $=86{,}400\ q$, where q is equal to the volume of water per second. v equals mean velocity in metres per second. E is the population, and c the proportion of the inhabitants who

regularly contribute to the sewers. In accordance with the above formula, a Table of coefficients has been constructed by the Author for a few of the large towns on the Continent. The coefficient thus obtained for Breslau is 1·8; for Paris, 1·9; for Cassel, 3·2; for Stuttgart, 4·8; while for Basel it is 395; for Mainz, 420; and for Linz, 617. These being the first four and the last three towns on the list. As the three first named cities have each of them to clarify their sewage before it is passed into the rivers, the Author suggests that five, as calculated by this formula, should be approximately the lowest coefficient to be attained by towns desirous of passing raw sewage into a stream. It is pointed out that these figures doubtless require correction for actual comparisons, and that probably the values v and c, instead of being simple numbers as here shown, may need to become complex figures or even powers. Further, for practical use, it is evident that accurate knowledge must be obtained respecting the length of river-flow needed for self-purification under various conditions; moreover, it is essential that the behaviour of bacteria of the nature of disease-germs should be studied, when exposed to the action of running water.

G. R. R.

Main Relief-Sewer of Brooklyn. By Willard Beahan.

(Transactions of the American Society of Civil Engineers, vol. xxvi., 1892, p. 484.)

This sewer has been constructed to relieve the main sewerage system, which has been overcharged by storm water. It was designed to receive the rainfall of an area of 1,300 acres, and it was assumed that 1 inch per hour might reach the sewer, the maximum rainfall being 4 inches per hour. The sewer is circular, of a diameter of 15 feet, of brickwork, and built on a grade of 1 in 1,000. In one portion, however, where there was not depth enough for a circular sewer, a segmental invert with side walls and a flat top of beams and jack arches has been used. The estimate of cost was £200,000, and was not exceeded. A length of 2,940 feet was built in open cut, and 9,340 feet tunnelled. These two sections formed separate contracts. The former was executed in less than six months, and the latter in less than eight. A large silt and trap-basin formed part of the former contract. The chief interest of the work lies in the method of tunnelling adopted, which was that called the "pilot system." The material was mainly sand and gravel with boulders. The Author discusses the relative merits, for the purpose in hand, of the various timbered systems, the shield system, and the pilot, and gives reasons for the preference shown for the last. As compared with timbering in the ordinary way, the pilot system has the advantage of using only short timbers and fewer of them, and of avoiding settlement of the ground; as compared with the shield it

is much less expensive in first cost when there are several working faces, it deals more easily with boulders, and it escapes the necessity of an iron casing. The pilot was cylindrical, 6 feet in diameter, composed of iron plates each 2 feet long, and of such width that six of them made up one ring of the pilot. It was kept in line by wedging. Steel poling-boards were used of plates 22 inches by 6 inches by $\frac{1}{4}$ inch, with a lug riveted to it for driving on by a hammer and bar. The pilot was driven at such a level as to allow men to stand on it to work, and was kept at its farther end some 40 feet in advance of the brickwork. As the excavation proceeded to the outer face of the brickwork, boards were put in and braced from the pilot. The details of the process are fully described, and various unforeseen difficulties that were met with.

The Paper is fully illustrated by ten sheets of drawings.

C. F. F.

A New Disinfecting-Apparatus. By O. Krell, Nuremberg.

(Gesundheits-Ingenieur, August 31st, 1892, p. 521.)

The apparatus herein described was designed by the Author in conjunction with Dr. Raptschefsky, at the instance of His Excellency Mr. v. Remmert, the inspector of the medical department of the Russian army. In the first instance all existing forms of disinfecting apparatus were procured and submitted to a searching trial. The conditions laid down for the apparatus to be constructed were :—

1. That it should destroy entirely, not only the germs of all known pathogenic organisms, but even those bacilli found to be the most difficult to exterminate (the garden-mould bacillus).

2. That the disinfection should be accomplished in the shortest possible space of time.

3. That the apparatus should be as simple as possible, both in construction and manipulation.

The various systems tested were: (1) by hot air; (2) by superheated steam; (3) by saturated-steam jets; (4) by saturated steam at rest at about atmospheric pressure, with means for producing a vacuum by condensation; (5) by saturated steam at rest, with means for creating high pressures during disinfection; (6) by saturated-steam jets at high pressure, with superheating. The performances of the various classes of disinfecting apparatus based upon the above principles are discussed in detail; and the experiments led to the conclusion that the new apparatus must work by means of saturated steam as a jet at high pressure, with provisions for ventilation of disinfecting chamber, and with special air-inlets also at the floor-level; without special heating-apparatus within the chamber, but furnished with heat accumulators. Diagrams are given of the apparatus as carried out to comply with these conditions. It is made of steel, and is cylindrical in form,

being 0·915 metre in diameter, and 1·52 metre in length (3 ft. × 5 ft.). The cylinder is placed horizontally, and has doors at each end, fastened to bronze rings with six screw-bolts to each. The chamber is tested to a pressure of ten atmospheres at the works, but the safety-valve is weighted to lift at $\frac{3}{4}$ atmosphere above normal.

The total weight of the apparatus is only about 20 centners (about 1 ton). It is distinguished from all others by its rapidity of working. The previous heating up of the chamber from the cold state takes two minutes; and in fifteen minutes more a temperature of 100° Centigrade is reached, even through a thickness of thirty-two blankets; while in five minutes more the temperature rises to 112°. It may therefore be asserted that the disinfection, even of the most difficult objects, can be completed in twenty-two minutes. The working speed is contrasted by the Author with that of other forms of apparatus now in use, and the advantage of saturated steam at 100° over heated air even at 150°, as determined by Koch, is insisted upon.

G. R. R.

Smoke-Prevention.

Report of the Special Committee of the St. Louis Engineering Club, U.S.

(Journal of the Association of Engineering Societies, Chicago, 1892, p. 291.)

The Authors of this report, having been charged with the duty of investigating the coal-smoke problem, while making such recommendations as may tend to abate the evil, which prevails to a very serious extent in the city of St. Louis, have given careful consideration to a number of general questions relating to the use of fuels which are everywhere applicable. Manufacturers and other large coal-users are, as a rule, disappointed with the results they obtain with such smoke-preventing inventions as have hitherto been devised. These inventions are in some cases unsuccessful because of an entire misconception of the principles involved in the combustion of bituminous coal, and in others because of a want of appreciation of the conditions which fix the limitations of successful application; and, lastly, the general public, when inveighing against the want of skill of manufacturers, engineers, and men of science, is too ready to assume that a smoking chimney necessarily represents wasteful combustion of fuel. It seems, then, that the whole community must be educated to a more intelligent understanding of the problem before a satisfactory solution can be successfully brought about.

Examining the principles upon which combustion depends, and the conditions under which smoke is produced or can be prevented, it is pointed out that although by the application of heat the

organic matter in coal is decomposed, and gaseous carbon and hydrogen given off, yet the heat may be insufficient to effect a chemical combination between those gases and the oxygen of the air, in which case further heat is not developed, but, on the contrary, absorbed. Again, when the hydro-carbon vapours are decomposed, carbonic acid and water ($CO_2 + H_2O$) may result from the complete combustion of some portion of them, while another portion has some of the carbon separated and set free, leaving a light hydro-carbon gas ($C_2H_4 = C + CH_4$). It is this separated carbon, in an incandescent state, which in the main causes the luminosity of the flame when a heavy hydro-carbon is burnt, and it is this same separated carbon which makes the visible smoke during the combustion of bituminous coal. For the rapid combustion of this separated carbon, not only is a strong oxidising action necessary, but a very high temperature as well, probably not less than 2,000° Fahrenheit. If this high temperature is not supplied in the fireplace, where the gases are generated and the carbon separated, the latter will be carried along by the rapid draught, and pass out unchanged as visible smoke; and, under the usual conditions of coal-combustion, it is impossible to attain such a temperature at once, because the coal is thrown into the fireplace in cold heaps, and generally in excessive quantities. Its moisture and combined water (together amounting to from 10 to 20 per cent. of the whole weight of the coal) have first to be volatilised, and while their vapour, mixed with a great volume of cold air, is passing off, a large quantity of the produced heat is absorbed.

Not one of the innumerable devices so far brought forward for the prevention of smoke is capable, in its present form and application, of fully meeting and satisfying all the requirements for success. The more important types are classified under the following seven heads:—A. Steam jets. B. Firebrick arches, or checker work. C. Hollow walls for pre-heating air. D. Coking arches or chambers. E. Double combustion. F. Downward-draught furnaces. G. Automatic stokers.

A.—The object of the steam-jet is to force air into the fireplace, either directly or after being heated, in sufficient quantity above the fuel-bed for the combustion of all combustible material, and to effect such a thorough mingling of the air, gases and carbon that combustion will take place readily, and not far beyond the fireplace. The steam-jet system can undoubtedly be made to yield satisfactory results where the demand upon the boiler is comparatively light and does not vary much; but with variation in the demands upon the boiler, the jets require corresponding adjustment, and such a system is therefore largely dependent upon the skill and care of the fireman. When the nozzles are not very carefully adjusted, they are apt to cause a blow-pipe action upon the boiler-shell or grate-bars, which results in a rapid burning of the metal, especially from the strong oxidizing action of the decomposing steam.

B.—Firebrick arches are usually placed near the rear end of the

fireplace, or over the bridge well. They cause the smoke, gases and air to pass through a constricted passage close to the fuel-bed, and serve not only to reflect the heat from it, but as a strong accumulator of heat, which tends to keep the heat up to a more uniformly high temperature. The checker-work is intended to produce the same result in a different way by dividing the general volume of smoke and gases into a number of small currents. With careful firing both these appliances can be made to produce good results, but only to a limited extent; and another and more serious objection is their want of durability and the consequent high cost of repairs and frequent interference with regular operations.

C.—A number of patents have been taken out based upon the system of providing hollow walls for pre-heating air, but the committee considers that they all fall short of the requirements.

D and E.—The systems classed under the heads of coking arches or chambers, and double-combustion, are also shown to be objectionable.

F.—Downward-draught furnaces consist essentially of a fireplace with the back closed, so that the smoke and gases can only pass away downwards through the fire-bed. This causes such intense heat upon the grate that instead of ordinary bars water-tubes have to be used, and these are so connected with the boiler-shell as to form a part of the water-circulating system, and supply so much additional heating surface. As they require to be at a greater distance apart than ordinary grate-bars, an auxiliary grate of ordinary type is sometimes set some distance below, into which the incandescent fuel falls from above, and through this all the air is delivered for completing the combustion of the gases issuing below the upper grate. Such a system is well adapted to insure a good smoke record, and it has the advantage also of being readily attached to a variety of boilers; but it is liable to defects in construction, while the water-tubes of the grate and the connecting pipes are subjected to unusual strains at the joints, and the latter are not altogether reliable. The system has, however, so many valuable features that it gives great promise for the future, and is well worth the attention and study required to secure the needed improvements.

G.—Automatic stokers are intended to secure regular and uniform feeding of coal to the fireplace by mechanical action, in place of the irregular and unreliable service of the ordinary fireman. The mechanical action may be applied in the form of screw or hopper feeders to fixed inclined grates, or to movable inclined or step grates. They require the coal to be properly sized as nuts or peas, and under favourable conditions are capable of giving good results, but their limitations are such that they cannot be regarded as applicable to any important extent.

It has been found in practice that, as a rule, all these devices for the prevention of smoke occasion a loss in the heating-power of the fuel. Experiments made at the New York Navy Yard with

four different types of nozzles, showed that the loss of steam, when steam-jet boilers were employed, was as follows:

	Single Round Hole of			Thirty-three Holes each of
	$\frac{1}{16}$ inch Diameter.	$\frac{1}{8}$ inch Diameter.	$\frac{9}{64}$ inch Diameter.	$\frac{1}{32}$ inch Diameter.
Per cent. of steam	Per Cent. 8·3	Per Cent. 12·0	Per Cent. 14·0	Per Cent. 20·7
Pounds of steam per hour . .	7·5	15·8	19·06	30·0
Loss in HP.	0·25	0·53	0·653	1·0

Some practical tests made in Chicago by the Chief Engineer of the Rookery Building, Mr. Wm. C. D. Gillespie, offer a further illustration of the losses due to smokeless combustion. The tests were divided into three series, each recording the average results reached by improvements in the furnace. They show both a decrease in power and a loss in economy the more they approach perfectly smokeless combustion.

Tests	First Series.	Second Series.	Third Series.
Duration of Tests . .	Four Days of Nine Hours each.	Five Days of Nine Hours each.	Five Days of Nine Hours each.
Pounds of coal burnt per square foot of grate per hour	24·34	24·59	23·82
HP. developed	102	93	89
Boiler ran above rating . per cent.	25	13	10
Conditions as to smoke	Moderate smoke	Smoke much reduced	Practically smokeless
Loss in power by reducing smoke . . . . . per cent.	..	12	15
Loss in economy by reducing smoke . . . " "	..	$7\frac{1}{2}$	$13\frac{1}{8}$

At the Home Cotton Mills steam-jets over the fire were tried as smoke preventors, and the result was an increase of 12 per cent. in the fuel consumption for the same work.

On the other hand, the amount of carbon even in dense smoke represents but a very small percentage of the weight of the coal under combustion. Mr. J. C. Headley passed through water all the gases from the flue of a boiler fired with bituminous coal producing a very black smoke, carefully collecting all the solid, which he dried and weighed. The amount of coal burnt was 12,890 lbs. or about $6\frac{1}{4}$ tons; the total weight of the gases

generated was 325,215 lbs., and the total quantity of solid matter contained therein was 42·63 lbs., of which not more than one-half was carbon. From this it appears that the separated carbon which made the smoke visible as a dense black cloud represented only about one-sixth of 1 per cent. of the weight of the coal used.

The greater part of the State of Illinois being underlaid by workable seams of bituminous coal, no other fuel can compete with it in economy; anthracite coal, coke and gas are in the matter of cost all out of reach for industrial purposes, but these are, nevertheless, recommended for domestic use, especially the two latter for cooking-purposes, with a view to reducing the smoke due to domestic fires, for the smoke nuisance affects the whole community and all are interested in getting rid of it. "All will admit," says the Report in conclusion, "that it occasions a great money loss in destruction of goods and furnishings, in defacement of buildings, in labour and material expended in the vain effort to keep clean, and in increased necessity for artificial light; an æsthetic loss through discouragement of the ornamentation of buildings, houses, and grounds; a sanitary loss in impaired health, and prevalence of lung and throat diseases; a population loss in those who cannot or will not live in a begrimed city; and last, not least, a moral loss in the effect on those who are forced to endure dirt and unwholesomeness."

The time has come when a decided step should be taken to enforce a remedy, and the Committee advises the appointment of inspectors, the making of tests and experiments with all devices for the prevention of smoke, and the enactment by the Municipality of Ordinances declaring the emission of dense visible smoke, subject to certain limitations, to be a nuisance involving stringent fines.

O. C. D. R.

Experiments on the Expansion of Continuous Rails.

By A. J. Moxham.

(American Street Railway Journal, 1892, p. 650.)

A length of 1,160 feet of one rail of a track already existing in a road-bed of good macadam was rendered rigidly continuous, by filling up the spaces between the rail-ends with distance-pieces specially cut to the rail-section, and clamping the rails together by two fish-plates 5 feet 4¼ inches long with eighteen bolts 1¼ inch diameter, turned carefully to fit each hole after it had been reamered through *in sitû*; the existing road-bed was therefore only disturbed for the portion necessary at each joint.

The temperature was measured at the rail-head, and at the bottom of 7-inch and 10-inch rails in an adjoining track, and it was found that the rails followed closely the air-temperature, so

that the surrounding road-bed has no effect in modifying the change of temperature to which the rail is subjected; and, further, most careful observations showed that the rail was absolutely stationary, so that the friction of the bed is sufficient to withstand the strains of tension or compression to which the rail was subjected by the variations of temperature, the maximum difference observed being 121° Fahrenheit between the months of March and August, viz., from 22° Fahrenheit below freezing to 89° Fahrenheit above.

As the track was connected up at the mean temperature of 40° Fahrenheit, the stress at the highest temperature would be less than 12,000 lbs. per square inch, and, therefore, well within the elastic limit.

It seems, therefore, possible to lay down a continuous rail with joints electrically welded or otherwise; though care would have to be exercised in repairing such a rail, as its state would be similar to that of a coiled spring.

The principal advantage claimed is, that much lighter rail-sections could be employed, as it is, at present, only the difficulty of the joints that causes the upward tendency in the weight of rails for street tracks.

F. J.

Statistics of the Fractures of Railway-Tires on the German State Railways from 1884 *to* 1890.

By — Bork.

(Verhandlungen des Vereins für Eisenbahnkunde, 1892, p. 48.)

The statistics of the fractures of railway-tires is interesting, showing, firstly, what a large number take place; and, secondly, in what direction steps should be taken to reduce them. Over a period of seven years, from 1884 to 1890 inclusive, for every hundred wheels 0·28 tires fractured; or, to put it in other words, more than one fracture occurred for every two hundred axles. In some cases the figures show even a worse result when classed under their various heads as follows:—

In 100 locomotive wheels,	0·5	fracture occurred,
„ 100 tender wheels,	0·65	„ „
„ 100 passenger-carriage wheels,	0·38	„ „

In 1890 alone in Germany, thirty trains left the rails through the fracture of wheel-tires, and there is no concealing the fact that herein lies a great source of danger, to diminish which every effort should be made. These efforts should be in two directions, first, to diminish the actual number of fractures; and, secondly, should a fracture occur, to prevent any portion of the tire breaking off, thereby diminishing the likelihood of the train leaving the rails.

The fractures may be due to the high stresses set up in the tires themselves, due to their being shrunk on and consequent contraction; but the Author holds that in general these high stresses do not occur frequently, and thinks the main cause of fracture to be more likely due to the hammering action of the rails.

The thinness of the tire has a very marked effect on the number of fractures, as will be seen by the following Table:—

For every 100 tires over 2·362 inches thick, 0·025 fracture occurred;
For every 100 tires from 1·968 inch to 2·362 inch thick, 0·08 fracture occurred;
For every 100 tires from 1·575 inch to 1·968 inch thick, 0·29 fracture occurred;
For every 100 tires from 1·378 inch to 1·575 inch thick, 0·54 fracture occurred;
For every 100 tires from 1·181 inch to 1·378 inch thick, 1·05 fracture occurred;
For every 100 tires from 0·984 inch to 1·181 inch thick, 1·65 fracture occurred;
For every 100 tires from 0·787 inch to 0·984 inch thick, 1·85 fracture occurred.

If the thinnest tires were from 1·181 inch to 1·378 inch the number of fractures would be considerably reduced. It must be admitted, however, that even now, with small thicknesses of tire the loss of material is considerable, and this would be increased with the greater thicknesses; but with the present perfection of manufacture the Author does not anticipate any difficulty in the manufacture of these heavy tires, and therefore holds that they should be applied to reduce the number of failures that occur. He quotes two further methods whereby the number of fractures may be reduced, (1) that of spring rings, which proved successful in one thousand one hundred and forty-six cases out of one thousand one hundred and ninety-seven; (2) by that of specially forced rings, which were successful in every case out of sixty-nine cases.

L. S. R.

The Siberian Railway. By B. Closterhalfen.

(Zeitschrift des Vereines deutscher Ingenieure, 1892, p. 1097.)

The Author, who bases his Paper mainly on information supplied by a member of the engineering staff of the railway, states that the works on the first section of the great trunk line across the Southern Provinces of Siberia, which is to connect St. Petersburg with Vladivostock, on the Pacific Ocean—a length of 6,478 miles (equivalent, approximately, to the distance from London to the Cape of Good Hope)—are now completed from Samara as far as Tschelabinsk, while considerable progress is also being made from the eastern end.

Full examination and consideration were given to three alternative routes; but the northern (*viâ* Nijni-Novgorod and Tjumen) entailing works of too costly a nature, and the southern (*viâ* Orenburg and across the Kirghiz steppes) being too much exposed to snowdrifts, choice was ultimately made of the middle route, the chief points of which are: Samara, Ufa, Slatoust, Tschelabinsk; Petropavlovsk, Omsk, Tomsk,—following the watershed of the great northern rivers. The line from Samara to Ufa was completed in 1888; from Ufa to Slatoust (traversing the southern portion of the Ural range, and forming the heaviest mountain section of the line) in 1890; and the extension from Slatoust to Tschelabinsk (the first town in Siberian territory, though politically included in a province of European Russia) is now ready for traffic; while the earthworks have been commenced on the further sections of the line through Siberia proper.

The Samara-Ufa section commences by a junction at Kinel, on the Samara and Orenburg line, about 25 miles from the former. It is a single line, 5 feet (normal) gauge, 300 miles in length, with maximum gradients eastwards 1 in 100, and westwards 1 in 125, the sharpest curve having a radius of 21·2 chains. Kinel is 600 feet above sea-level, the summit of the line 1,693 feet, and the terminal point, Ufa, 872 feet. All the constructive material came from Russia, and, with the exception of the sleepers and rails, which were delivered forward on the line itself, were brought by water during the summer to the nearest available point, and thence by cart or sledge. To guard against snowdrifts, the line is (where on the surface) made throughout at some height above the ground. There are two hundred and nine bridges on the line, the largest having 6 spans of 351 feet each, over the Belaja. The rails are steel, weighing from 61 to 65 lbs. per yard. At 2 miles' intervals and at every level crossing, of which there are two hundred and sixty-seven, are watch-houses for the permanent-way staff; while the maximum distance between two stations, of which at present there are twenty-five, is 20 miles. The workshops, carriage-sheds, &c., are at Ufa. The rolling-stock comprises thirty-one six-wheeled engines (32 tons) for passenger-service, and twenty-nine eight-wheeled engines (42 tons) for goods; one official carriage, thirty-one ordinary passenger-cars, and four special prison-cars; with various descriptions of goods-waggons. The maximum service would be nine trains each way daily.

From Ufa to Slatoust, in a direct line, is 143 miles; but the length of the line is 198 miles. There are some heavy cuttings in disintegrated limestone; the highest bank is 95 feet, and deepest cutting 68 feet, the average quantity of earthwork being 88,000 cubic yards per mile. Maximum gradient eastwards equals 1 in 100; ditto westwards, 1 in 118. Minimum radius of curve equals 16 chains. The line from Slatoust to Tschelabinsk (103 miles long) rises for about 10 miles to the eastern ridge of the Urals, then falls to the open country. The earthworks are light, and the line presents no features of special interest.

The distance for which railway communication is now completed is therefore:—

	Miles.
St. Petersburg to Samara	888
Samara to Tschelabinsk	626
	1,514

The further lengths of the Siberian line proper are as follows:—

	Miles.
1. West Siberian line—Tschelabinsk to Tomsk. . .	1,204
2. Middle „ „ Tomsk to Irkutsk	1,053
3. Baikal loop line—Irkutsk to Verchne-Udinsk . .	194
4. Trans-Baikal line—Verchne-Udinsk to Sretensk .	667
5. East Siberian „ Sretensk to Grafskaja . . .	1,586
6. Ussuri line—Grafskaja to Vladivostock	260
	4,964

making in all, 6,478 miles.

Of the above, sections 3 and 5 are intended to be deferred for a time; for, although the complete continuity of the line is essential to its fullest utility, these intermediate links, covering a distance of 1,780 miles, are for the present to be supplied by a service of steamers on Lake Baikal and on the Amur respectively. The length of line to be constructed is therefore 3,184 miles.

On the West Siberian line it is proposed to run three trains each way daily at an average speed of 16 miles per hour; but the number can easily be raised to seven. In open country the maximum gradient is 1 in 125, and minimum radius 35½ chains, the rails weighing 48½ lbs. per yard. In mountain sections the maximum gradient is 1 in 50 (this, however, is quite exceptional), and minimum radius 17 chains; rails equal 54½ lbs. per yard. The works on this section are now in progress. The terminal point is at the crossing of the River Tom, from which a branch, 47 miles in length, runs to Tomsk.

The middle Siberian line calls for no special notice. The line round the southern shore of Lake Baikal, from Irkutsk to Verchne-Udinsk, runs through a beautiful country, but necessitates very heavy works, comprising three hundred and thirty-one bridges of a total length of 3,412 yards, numerous tunnels (of which the longest is 2½ miles), and rock cuttings to a depth of 120 feet. The estimated cost is £18,266 per mile, and temporarily, therefore, a service of steamers will make the connection across the lake.

The Author then proceeds to describe the topographical and climatic features of the country traversed by the Trans-Baikal and East Siberian sections of the line.[1]

The Usuri line—the last section eastwards—is now in construction, and the works are being pushed forward as rapidly as pos-

[1] For fuller information on this subject, see Minutes of Proceedings Inst. C.E., vol. cvi. p. 280.

sible. The estimated cost of the line is £3,000,000, and the amount allotted to the work during the present year (in spite of general financial difficulties) has been upwards of £1,100,000.

The following comparative extracts refer to the sections already completed:—

—	Samara—Ufa.	Ufa—Slatoust.	Slatoust—Tschelabinsk.
	£.	£.	£.
Total cost per mile . . .	12,325	14,825	11,925
Earthworks per mile . . .	2,254	4,540	3,695
Bridges and culverts per mile	2,594	3,698	2,512
Permanent way per mile. .	2,891	2,958	2,552
Rolling stock per mile . .	1,822	720	524

While the railway communication remains interrupted by the two sections of waterway, the journey between St. Petersburg and Vladivostock will occupy twenty-four days; but the work is being pushed forward as an essentially strategic line to dominate Chinese territory and support the naval force on the Pacific, and the Government is making every effort to ensure the early completion of the work.

P. W. B.

On New Mountain-Railways. By Professor Göring.

(Verhandlungen des Vereins für Eisenbahnkunde, 1892, p. 4.)

The Author notes the great development that the mountain railways have taken of late, and classes the various systems under two heads.

I. Cog-wheel railways with cog-wheels alone, or in conjunction with the ordinary adhesion-wheels.

II. Wire-rope driven railways, which are, however, usually fitted with cog-wheels as a measure of safety.

The first real practical application of the toothed-wheel was at Mount Washington in 1867,[1] where the greatest incline is 1 in 3. In 1871 Riggenbach's patent was successfully applied in the Vitznau-Rigibahn and in 1873[2] in the Arthrigibahn. The Author then enumerates a number of other lines that were carried out with a short notice on each line. Since 1882, Abt's system has met with considerable success and application, its multiple-toothed

[1] Minutes of Proceedings Inst. C.E., vol. xcvi. p. 260.
[2] *Ibid.*, vol. xxx. p 103.

rack having many advantages. The rack consists of two or three 0·708-inch to 1·811-inch thick soft steel plates, placed about 1·811 inch apart, with teeth cut in most carefully, so as to avoid undue friction and backlash. The multiple rack allows more teeth to be in gear at once, and therefore reduces the pressure that each tooth has to support.

To minimize the unavoidable inequalities and consequent shocks, stout steel springs are fitted so as to allow the racks to yield slightly, say $\frac{1}{8}$ inch for 1·3 ton. This arrangement greatly reduces the wear both on the rack and on the toothed-wheels.

The double horizontal toothed gearing has been used by Locher in the Pilatus rail, with gradients 1 in 2·08; but the vibration shows that, although the line is perfectly safe, wire-rope driven railways, where such steep inclines occur, are preferable.

The locomotives for lines where cog-driving alone is used are very simple, the motion from the steam-cylinders being transmitted either by levers or by intermediate cog-gearing.

Mr. Abt has designed a mixed locomotive for traction by adhesion and cog-gearing, having four steam-cylinders; the two inside cylinders drive the cog-gearing, and the two outside ones the ordinary coupled adhesion wheels. Having the two systems completely separated has many advantages, especially that of simplicity. The locomotives are very economical, and on account of the smallness of the cylinders driving the cog-wheels, the blast is very efficient. The locomotives can exert about 187 indicated HP., having 516·4 square feet of heating-surface, *i.e.*, about 0·362 indicated HP. per square foot of heating-surface, whereas an ordinary goods locomotive, at the same speed, may, according to Frank, be taken as exerting 0·187 indicated HP. per square foot of heating-surface.

One of the most recent lines is that from Eisenerz to Vordenberg, in Austria, which was opened in 1891; it is 12½ miles long, and has nearly 9 miles of cog-gearing. There are two 1·063-inch plates in the rack composed of soft steel plate. The locomotives weigh 54·5 tons ready for service, and will draw a 100-ton train at the mean speed on the entire line of 6·31 miles per hour. They have six-coupled ordinary-adhesion wheels, and two-coupled cog-geared axles; the total heating-surface is 1,560 square feet, of which 96·8 square feet are direct heating-surface; there are 22·6 square feet of grate-surface, and the working pressure is 156 lbs. per square inch. The lines to Zermatt and over the Brünig are also dealt with.

The coming into gear of the cog-wheels is always a difficult problem, and Mr. Abt's method of placing the last length of rack on springs is described.

The second head, or cable-driven railways, is represented by the Lugano line and others, including the line to the top of San Salvatore, where the power is supplied by turbines and electrical motors; the line is in two distinct portions, with a changing-station at the centre, one car always remaining on the upper half,

while the other car remains only on the lower half; the passengers changing cars at the changing-station.

The brakes are so arranged that, should the cable slack in the slightest, they immediately come into action, or the guard can apply them by hand if desired.

The Paper is accompanied by plans of the locomotives and other matters referred to in the Paper.

L. S. R.

The New Workshops with Electric Motors of the Northern Railway Company of France. By F. Géraldy.

(La Lumière Électrique, vol. xlv., 1892, p. 603.)

The Company referred to, having decided to move a small shop used for their telegraphic service into a position more convenient, and at the same time to utilize an old wooden shed which would have required considerable strengthening if shafting, etc., had to be accommodated, it was decided to drive the tools by electrical transmission, and to supply each tool with its own independent motor. The current is supplied by the "Société d'Éclairage et de Force," whose generating-station is in close proximity, at a price of 0·38 franc per kilowatt-hour ($3\frac{1}{2}d.$ per Board of Trade unit). This shop has been running now for a year, and the mean daily consumption has been about 11 kilowatt-hours; so that the daily expense for current is 4·18 francs, or for power, including depreciation of motors, oiling, renewal of brushes, etc., 5·18 francs per day (4*s.* 2*d.* per day). In the former shop a gas-engine had been used, and, under the same conditions, the price for power was a little more than 13 francs per day (10*s.* 4*d.* per day). The price paid for the current is certainly specially low; but, even taking the price of 0·45 franc per hour (6*d.* per Board of Trade unit), as charged in Paris for an electrical HP., the daily cost would amount to only 6·71 francs (5*s.* 5*d.*), or still at an economy of 50 per cent. over the gas-motor. The Paper is illustrated with sketch-plans, showing the application of the motors to lathes, a radial drill, a shaping-machine, a grinder and mixer for paint, and a ventilating-blower; and a complete tabular statement of the electrical-power absorbed when running empty and on load is presented, varying according to the particular tool from $\frac{1}{3}$ to $2\frac{1}{4}$ HP., exhibiting at a glance the great saving in power which is claimed for the adoption of independent electrical motors in such cases where the work is intermittent, and the motor can be cut out of circuit when not required. This statement and the principal data are taken from a communication to the "Revue générale des Chemins de fer" made by Mr. Sartiaux, the manager of the Company.

F. J.

On the Ventilation of Long Tunnels and a Proposed System of Artificial Ventilation. By Marco Saccardo.

(Giornale del Genio Civile, 1892, p. 141.)

The Author discusses at considerable length (1) the chief conditions affecting the natural ventilation, and requiring to be studied in the artificial ventilation, of tunnels; calculating the effect of varying cross-section, of gradients, alterations of incline, curves or bends, and working conditions incidental to the loads as affecting consumption of fuel and the products of combustion—*i.e.*, the degree of vitiation of the atmosphere, and consequently (2) the quantity of air necessary for proper ventilation, the pressure due to natural conditions and requisite for artificial ventilation. The various systems which have, up to the present time, been proposed for the latter purpose are then reviewed: comprising the creation of artificial currents by (1) heat; (2) suction, and (3) pressure or compression; also (4) the adoption of doors to be closed or opened as required (a system of doubtful benefit and attended with serious risks), and (5) the construction of lateral conduits or air-tunnels to supply pure air to any central part of the tunnel. In the case proposed for the Simplon tunnel the cost of such an air-conduit would be little short of £250,000.

The Author suggests that the system which he proposes offers a generic solution of the whole problem. At the mouth of the tunnel, or at any point on its length, he proposes to create an artificial variation in pressure of the air-current to any extent requisite by the construction of an annular chamber encircling the tunnel itself, and with a concentric bell-mouth, resembling a truncated pyramidal cone. By a centrifugal air-pump the air accumulated in this chamber would be discharged, in the form of a pyramidal film or curtain of air impinging on the current through the tunnel, at a velocity or pressure sufficient, in the first place, to oppose an obstacle to any counter-current; and, with increased pressure, to drive it back, and thus to regulate or control the course of the ventilation as required by any varying conditions of atmosphere or of traffic. The reasoning of the process is sustained by full calculations, which have been amply supported and corroborated by experiments on large-scale models. The pumps can be arranged for suction or for pressure, or for both simultaneously or alternately. On steep gradients it would be preferable to drive the current towards the ascending train, to assist the dispersion of any asphyxiating volume of air. The pressure of the currents at any point of the tunnel would be transmitted from anemometers to the engine-room, and currents could be created whenever the natural ventilation is deficient or their velocity regulated—increased or moderated or checked—as requisite. For ordinary purposes (in the long Alpine tunnels chiefly in question), 75 HP. would be sufficient, while 200 HP.

would reverse the strongest natural current. The cost of the work would be very moderate; while to supply air direct (through a lateral conduit of sectional area equivalent to the annular orifice) to a central point of, for example, the Mont Cenis tunnel would require 1,140 HP.; or, taking the work to be performed by a 75-HP. engine, the air conduit would have to be of far larger sectional area, and would cost over £480,000, while its sole function would be to clear the air, but not to control the currents.

The Author then proceeds to consider artificial ventilation in shafts and wells, and the limit of usefulness of shafts in long tunnels, and appends in conclusion a series of tables of barometrical observations.

P. W. B.

On the Determination of the Mechanical Equivalent of Heat.

By C. Miculescu.

(Annales de Chémie et de Physique, vol. 1892, p. 202.)

The Author first describes the results of previous determinations. The methods employed have been either (1) direct, that is, methods in which a measured quantity of work has been expended, and the heat produced has been ascertained; or (2) indirect, physical quantities being measured which involve J according to relations established by thermodynamics.

Joules' direct experiments with Rowland's corrections give J = 426·9 for temperatures on the air thermometer, and the latitude of Baltimore. This corresponds to 426·5 for the latitude of Paris (metric units).

Rowland's values, also by the direct method, are:—

Temperature	5°	10°	15°	20°	25°	29°	30°	36°
Value of J .	429·8	428·5	427·4	426·4	425·8	425·5	425·6	425·8

The diminution with increase of temperature is explained by the variation of the specific heat of water.

The Author then describes experiments of his own made by the direct method, so arranged as to be a zero method. He reduced the time necessary for a determination to a few minutes, at the same time increasing the accuracy of the measurements (1) by operating with a considerable amount of work (1 HP.), (2) by using very delicate thermometric instruments and a calorimetric method not requiring corrections. The dynamo which drove paddles in a water-cistern was so suspended as to form a dynamometer. The quantity of heat was measured at constant temperature. Round the calorimeter proper, in which the water was churned by the paddles, circulated a current of water, so regulated that the calorimeter did not rise in temperature. The apparatus was placed in the vaults of the Physical Laboratory at the Sorbonne.

In reducing the results the Author assumes that between 10° and 13° the specific heat of water may be taken as unity.

A Table is given of the results of thirty-one determinations, which differ very little from each other. The general mean value of all the experiments is—

$$J = 426{\cdot}7 \text{ kilogrammetres}$$

for the latitude of Paris, and temperatures by air-thermometer.

The International Committee of Weights and Measures has adopted as the normal thermometric scale that of the hydrogen thermometer. Correcting to that scale,

$$J = 426{\cdot}8 \text{ kilogrammetres.}$$

W. C. U.

On the Calculation of Flame-Temperatures. By E. Blass.

(Stahl und Eisen, 1892, p. 893.)

The Author has been induced to undertake experiments on the large scale, upon the heat attainable by gas-flames, from the circumstance that platinum can be brought to the welding point, but cannot be melted in a crucible furnace, by the combustion of cold gas with cold air, which should, according to the old formulas, give a sensible temperature of 2,650° Centigrade, or far above the melting-point of the metal (1,775° according to Violle). This difference is due to the assumption that the specific heats of the products of combustion, water and carbon dioxide, are constant; whereas these values actually change very rapidly with increased temperature in both gases, the expressions for their mean value being, according to Le Chatelier,[1] as follows :—

$$CO_2 : c^p = 0{\cdot}188 + 0{\cdot}000273\,t - 0{\cdot}0000000537\,t^2$$
$$H_2O : c^p = 0{\cdot}420 + 0{\cdot}000364\,t$$

Calculated in this manner, the temperature attainable by burning water-gas with air is approximately 1,700°, a result sufficiently near to the value obtained by Violle's direct experiment to establish the probable correctness of the Le Chatelier formula; but in order to test the point more completely, a set of experiments have been carried out at the joint cost of the German Iron Smelters' Society and the European Water-Gas Company, with water-gas supplied by Messrs. Schulz, Knaudt and Co., a fuel selected as being of simple and uniform composition. The

[1] Annales des Mines, vol. iv., 1883.

apparatus consisted of a four-twyer crucible melting-furnace, containing an empty steel melting crucible, with four tubes perforating the side at right angles to each other. Three of these tubes contained pyrometers, while the fourth took off a portion of the products of combustion to a condenser and gas-meter, in order to determine the amount of water, and other constituents, formed by the combustion. The gas-supply was measured by two gas-meters of 50 and 100 cubic metres capacity per hour respectively, and the air supplied by Root's blowers, driven by variable speed pulleys, each step corresponding to a difference of 100 cubic metres per hour. The composition of the furnace gases was deduced at short intervals by analyses of samples taken directly from the furnace, as well as from the portion poured through the meter. These, although conducted with extreme care, showed that the relative proportion of water to carbon dioxide was subject to variation within rather wide limits, and that gases do not mix as rapidly and uniformly as they are generally supposed to do.

The supposed instruments used for direct measurement were :—

1. Wiborgh's air-thermometer, which can be used up to 1,200° Centigrade.

2. Le Chatelier's electric pyrometer, available nearly up to the melting point of platinum.

3. Hartmann and Braun's telephone pyrometer.

Besides these, Siemens' calorimeter pyrometer, Seeger's normal cones of clay and quartz, Ducretel's optical pyrometer, and Prinsep's pyrometric alloys of gold and platinum, supplied by the Frankfort Gold and Silver Refinery, were used on different occasions. The air-thermometer, though most exact in principle, was not very satisfactory, two different instruments giving dissimilar indications, without its being possible to discover the cause of the difference. The telephone pyrometer was found to be very convenient in work, but unfortunately it was destroyed at an early period of the investigation by a quantity of molten copper falling upon the platinum case. It is an excellent instrument, the only defects being the high price (£20) and the difficulty of using it in a noisy place.

The Le Chatelier pyrometer is also a very handy instrument, but the thermo couple alters tolerably rapidly, so that the scale indications cannot be relied upon for any great length of time, and the recording galvanometer is so sensitive to vibrations that it can scarcely be used in any place where machinery is at work.

The Ducretel polariscope is scarcely to be regarded as a pyrometer, as no correct measure of temperature can be obtained from it, although in experienced hands it may be of value in comparing different sources of heat. Considerable experience and sensitiveness of the observer to slight changes of colour are essential for its successful use.

The Prinsep alloys in all cases gave results agreeing very well with those obtained from the Wiborgh and Le Chatelier pyrometers.

After overcoming a variety of preliminary difficulties, the apparatus was brought into regular working order, and numerous experiments were made, each extending over a period of from eight to ten hours. The data and methods of computation are given in detail, together with the results obtained from five experiments, each representing a different condition of combustion, two being with gas in excess, two with air in excess in variable proportions, and the fifth with gas and air in the theoretical proportions required to produce the highest calorific effect. The results are tabulated as follows:—

Temperature.	Gas in Excess.		Air in Excess.		Gas and Air in Theoretical Proportions.	
	I. Gas : Air 1 : 0·18	II. Gas : Air 1 : 0·714	III. Gas : Air 1 : 9·79	IV. Gas : Air 1 : 4·18	V. Gas and Air cold.	VI. Gas cold, Air 840°
Observed	425	1,170	655	1,218	>1,775	<1,775
Calculated by new formula. . . .	409	1,173	688	1,235	1,690	1,947
Calculated by old formula. . . .	521	1,560	747	1,890	2,630	2,916

In the fifth experiment with gas and air in proportion for theoretically perfect combustion, the loop of the thermopile in platinum rhodium alloy was twice melted, but a platinum wire of 1 millimetre diameter, and the gold platinum alloy No. 24, whose reputed melting point is 1,690°, showed only superficial fusion.

The experiment in the sixth column was made by Mr. Dicke at Mr. Pintsch's works, the gas being burnt with air heated to 840° Centigrade, as determined by a Wiborgh pyrometer. In this case platinum was completely melted, the temperature realized being more than sufficient for the fusion of the best Dahlhausen fire-bricks, and could only be resisted by a magnesite lining to the furnace.

A point of interest in Experiment II is the circumstance that both copper and iron were oxidized in the flame, although the latter contained about 40 per cent. of reducing gases (carbonic oxide and hydrogen). It is evident, therefore, that to obtain a flame in which iron will not oxidize the gas excess must be much larger, as in Experiment I, where, however, the heat realized is too low for any but very limited uses. The Author suggests that possibly a non-oxidizing white heat, or 1,400°, might be realized by the conditions of Experiment I if both gas and air were brought to a temperature of 1,000° before combination.

In order to form an idea of the temperatures attainable by the combustion of different mixtures of gases, the Author has compiled the following Table of theoretical temperatures, the fuel being supposed to be chemically pure:—

—	Gas and Air cold.	Gas cold, Air 1000°.	Gas 1000°, Air 1000°.
Producer gas	..	..	..
$\frac{1}{3}$ Vol CO + $\frac{2}{3}$ Vol N	..	..	..
Water-gas	1,450	1,750	2,160
$\frac{1}{2}$ Vol CO + $\frac{1}{2}$ Vol H	1,875	2,270	2,400
Hydrogen	1,650	1,970	2,140
Carbonic Oxide	1,955	2,390	2,570

When the above value for theoretical water-gas, 1,875°, is compared with the 1,690° found by experiment, the difference is seen to be only 185°, or about 10 per cent., whereas the difference between the 2,160° calculated for producer-gas and 1,500° observed by Le Chatelier as the maximum heat of the Siemens furnace, or 660°, represents nearly 30 per cent. The reason for this is to be sought, not in the non-development of the calorific value of the fuel in practice, but in retarded combustion, owing to the gradual mixture of the air and gas, so that the heat is distributed over a large area, with a corresponding diminution of maximum intensity, whereas when gas and air are burnt under the conditions of the experiments, both being supplied under pressure, combination is rapidly effected, with the result of producing a focus of intense temperature.

In the final part of the Paper the Author, after quoting calculations from Campbell's Paper on "The Physical and Chemical Equations of the Open-Hearth Furnace," in the Proceedings of the American Institute of Mining Engineers, June 1890, which show how small a proportion of the heat developed in the Siemens furnace is actually devoted to melting the charge, suggests that this might be improved if the gas and air could be supplied as a blowpipe flame of sufficient intensity to displace the surface covering of slag and penetrate to the bath, which would readily take up heat by reason of its high conductivity.

As a means of simplifying the calculations of flame temperatures the Author has computed the specific heat of water and carbonic acid by the Le Chatelier formula for different temperatures, as given in the following Table:—

Temperature	0	200	400	600	800	1,000	1,200
Carbonic acid	0·188	0·240	0·288	0·332	0·372	0·407	0·438
Water vapour	0·420	0·493	0·565	0·637	0·711	0·783	0·856

Temperature	1,400	1,600	1,800	2,000	2,500	3,000
Carbonic acid	0·465	0·488	0·507	0·520	0·534	0·524
Water vapour	0·929	1·002	1·075	1·148	1·340	1·512

The specific heat of oxygen (0·217°), nitrogen (0·244°), hydrogen (3·409°), and carbonic oxide (0·245°), although not perfectly constant with increase of temperature, are sufficiently so for practical purposes of calculation.

The effect of dissociation may also be disregarded, as, according to Mallard and Le Chatelier, it does not affect water vapour below 3,000°, and in carbonic acid it only begins at 1,800° or 2,000°, the amount of decomposition being about 4 per cent. at between 2,640°, 17 per cent. at 2,646°, and 61 per cent. at 3,130°, the temperature of complete dissociation being probably at 3,400°.

H. B.

Apparatus for Cooling the Condensing-Water of Steam-Engines.

(Le Génie Civil, vol. xxi., 1892, p. 316.)

The apparatus here described was designed to meet a certain case where, a condensing-engine of 70 HP. having been erected, it was found that condensing-water could not be obtained in sufficient quantity. A tank was made 6 feet 3 inches by 3 feet 6 inches by 2 feet 4 inches. This was divided up by wooden partitions 4 inches apart. The warm water was delivered on the top edges of these partitions and trickled down them, while a very strong current of air was driven upwards between the partitions from a fan 3 feet 11 inches in diameter. A vacuum of 27½ inches to 28 inches of mercury was easily obtained.

The air acts in two ways—by absorbing heat itself and by causing evaporation of the water and thus cooling the remainder. In winter the former action is the more effective, and in summer the latter, the net result being constant throughout the year. The condensed steam from the cylinders is sufficient to make up for the vapour carried off.

The air-pressure is that of 0·2 inch of water, and its velocity 21 feet per second. The process can be made more effective by having two sets of partitions at right angles to each other, so as to break up the air-currents.

A better vacuum is obtained by using the same water repeatedly, because in its first passage through the air-pump the water gives up the air it contained, and the cooling process leaves it still practically free of air.

C. F. F.

Brick Arches in Fire-boxes, Illinois Central Railroad.

(Railroad Gazette, New York, October 7, 1892, p. 741.)

Owing to the efforts of the Society for the Prevention of Smoke in Chicago[1], the Illinois Central Railroad has fitted all its locomotives with some one of the types of steam-jet apparatus recommended by the Society; but, finding these only moderately satisfactory, has commenced the use of an extra brick arch and of a deflecting door, in addition to the ordinary inclined arch. In a locomotive with a long fire-box there are two additional arches placed nearer the furnace door, and only 10 inches wide, the fire-box being $101\frac{3}{16}$ inches long; the inclined arch extends about 32 inches from the tube-plate, the first narrow arch being placed 20 inches further back, and the second a further 25 inches. In shorter boxes only one additional arch is used; and, while both arrangements are satisfactory in preventing smoke, there is also an economy of fuel; and the whole of the locomotives of the line are to be fitted with these arches as rapidly as possible.

W. H. B.

Grain-Elevators at Galatz and Braila. By C. Arndt.

(Zeitschrift des Vereines deutscher Ingenieure, 1892, p. 973.)

The extensive grain-elevators and stores erected by the Roumanian Government at Galatz and Braila, on the Danube, at a cost of £850,000, are the first works of the kind carried out at the public expense by any European State. The output of grain (chiefly maize, oats, barley, and rye) had increased from 1,324,000 tons in 1880 to 1,952,000 tons in 1888. About half this quantity is exported by the Sulina mouth of the Danube, the process of transhipment from the railway, or storehouses, to sea-going vessels taking formerly from three to four days. The ports on the Black Sea coast are not yet developed, though the railway from Cernavoda to Constanza is in course of construction.

The works at both Galatz and Braila are carried out on the same type. The site is on soft ground, on the northern bank of the Danube, necessitating heavy foundations. The dock basin is 1,640 feet long and 394 feet wide, and has at low water a depth of 16 feet 6 inches, sufficient for all vessels passing Sulina. The works, as planned, comprise two large store-buildings, each 394 feet by 92 feet, 59 feet 6 inches in height, and 115 feet back from the quay. At present one building only has been erected, but all provisions are made in working-arrangements for the completion of the scheme. The building is entirely occupied by the siloes, or hopper-shafts, which are hexagonal in plan and constructed

[1] *Ante*, p. 442.

of iron framing with wire-work filled in with cement. About three-fourths of the shafts are 11 feet 6 inches in diameter, the remainder being 8 feet 3 inches; the height of the shafts is 55 feet 9 inches above the crown of the basement tunnels. Four towers at the angles of the building accommodate the elevators and gearing for all the machinery required. The building-site is covered by 5 feet of concrete, at a depth of 23 feet, resting on five thousand piles. The basement consists of nine parallel tunnels, corresponding to the rows of shafts above, and these are framed in three rows of hoppers, which discharge over as many automatic conveyors or endless travelling bands. The same system of distribution feeds the shafts above. At each end of the building a transverse tunnel connects with a longitudinal tunnel, 8 feet 3 inches wide and about 9 feet in height, running along the back of the quay wall, and again connected with a number of wells or shafts about 20 feet deep. All connections are duplicated, so that both upper and lower bands, travelling in opposite directions, are utilized. The grain can thus be passed from a railway wagon by the elevators to any shaft, thence by the basement tunnels to either end of the building, and by the transverse tunnels to the quay-tunnel and to any of the wells. From these it can be lifted by telescope elevators and discharged into the hold of any vessel. The reverse operation can proceed simultaneously, *i.e.*, from any vessel along the quay to any portion of the building, or to the cleansing machinery, or from these back to the hoppers. The loading and unloading on the quay is effected by two travelling elevators. One of these, running on a gauge of 11 feet 6 inches, and mounted on a turn-table, has a long overhead gallery in which run automatic conveyors; from one end hangs a telescope tube with bucket-elevator, which can be lowered either into the vessel's hold or into the wells supplied by the longitudinal tunnel; the other end carries a tubular shoot for delivery to either vessel, or wagon, or well. The capacity of the elevator is 150 tons per hour; the platform carries a 35-HP. engine (of marine type), with vertical boilers, feed-tanks, windlass, &c., the whole being enclosed in framing covered with corrugated iron. A second elevator, of similar capacity and engine power, but not provided with rotary movement, has a vertical elevator for taking grain from the wells, and an adjustable inclined shoot to deliver into a vessel's hold in any position.

The engine-house stands midway between the sites of the two blocks of buildings, and the power is transmitted by wire-ropes. The elevators and general machinery take (in the one building) 270 HP., and the cleansing machinery (which is arranged in two groups dealing each with 150 tons per hour) takes 80 HP. The largest engine is of 500 HP.; high-pressure cylinder, 25·8 inches diameter, low-pressure ditto, 51·6 inches diameter, and stroke 49·2 inches. Number of revolutions, 60 per minute. There is also a 50-HP. engine for the electric lighting, but during the day, when the tunnels only require illumination, the circuit is coupled

on to the large engine. The trucks and wagons are moved over the whole of the sidings by hydraulic capstans, at a pressure of 735 lbs. per square inch.

There is also a floating elevator of 35 HP., mounted on a pontoon 124 feet 8 inches in length and 27 feet 10 inches beam, and used for transhipping from one vessel to another, having one vertical telescope elevator and one adjustable shoot.

P. W. B.

The Extension of the Ernst-August Adit-Level.

By O. Brathuhn.

(Berg- und Hüttenmännische Zeitung, 1892, p. 293.)

The deepest adit-level of the Upper Harz, the Ernst-August adit-level, has, by the construction of a new branch from the Johann-Friedrich shaft at Bockswiese to the Güte des Herrn shaft at Lautenthal, received an addition in length of 4,345 metres (4,753 yards), so that its total length now amounts to 27,035 metres (29,576 yards). The branch was driven in three sections, the first of which, 3,210 metres (3,512 yards) in length, from the Schwarzen mine at Lautenthal to the Johann-Friedrich shaft, is of interest from an engineering point of view. On account of the dense vegetation, the relative position of these two inclined shafts was not determined by a special triangulation, but was deduced from the results of the Ordnance Survey. In this case the triangulation points of the Ordnance Survey served for the first time as the sole basis for so important a piece of underground work. The first determination of the floor-level was made by Borchers in 1876. As, however, in driving the Lautenthal section the floor became somewhat higher and the adit somewhat shorter than was originally planned, the levelling was repeated. The Lautenthal end was found to be 200 millimetres (8 inches) higher than it should have been, and this error was balanced off by a slight increase in the gradient in the Lautenthal section before holing. The transference of a point from the surface into the mine was effected by means of the inclined shafts, 336 metres (1,100 feet) and 203 metres (670 feet) deep respectively, and the orientation of the two sections, respectively 1,490 and 1,820 metres (1,630 and 1,991 yards) in length was effected by means of the magnetic needle. After holing it was found that the azimuth of the last line of the traverse in one section deduced from the last line in the other presented the slight error of 1 minute 8 seconds. The accuracy of this survey does not exceed that attained in the older portions of the Ernst-August adit. Thanks to previous experience and to improved magnetic instruments, however, it was possible to make the survey with greater certainty and in less time. The method of employing powerful magnets before the

holing was found unnecessary, as a test of the direction determined a year previously with the aid of the magnetic needle, gave an exact coincidence with the direction originally found. This survey affords an illustration of the accuracy with which the surface and underground surveys may be connected by means of magnetic instruments.

B. H. B.

On the Microscopical Research of Metals.

By Professor Martens.

(Verhandlungen des Vereins für Eisenbahnkunde, 1892, p. 67.)

The investigation may be conducted on the actual fractures of the test-specimens, or on specially prepared test-slides. All those treated of in the Paper are of the latter kind, as using the plain fracture under the microscope does not give very satisfactory results. The Author, however, adds a description of the method of employing the simple fractures.

The foundation or cement, in which the specimens are placed for polishing, and the polishing material must be prepared with great care, and varies according to the hardness of the specimen to be prepared. For rough polishing the Author uses fine emery. The fine polishing is done by hand on glass, cast-iron, copper, or lead plates prepared in a special manner.

The polishing powder may be of almost any good polishing material, but has to be extremely carefully prepared, as the grains must all be of one size. To prepare this, the Author employs inverted conical glass vessels with a small aperture in the apex of the cone; and the polishing material, being mixed with water, and occasionally shaken up, passes through this aperture, and is divided into different sizes and numbers, according to the time taken to settle. The finest kinds are mixed with spirit or ether.

To polish the specimens, which are about $\frac{1}{2}$ inch square and a bare $\frac{1}{16}$-inch thick, several of them are cemented side by side in a conveniently compact form, and an ordinary glass-lens-polishing machine is used to polish them; or they may be polished by hand. The specimens are then taken out and thoroughly cleaned from any particles of cement that may be adhering to them by means of ether.

The colouring of the specimens can be done in various ways, and is one of the principal points to be attended to in microscopical research. The Author recommends having several similar specimens under observation at the same time, with different degrees of colouring in each.

The colouring brings out the various constituents of the material, and foreign substances contained in the interstices, *e.g.* ash, etc., and renders them distinct and visible from one another,

which they would not be were it not for the colouring matter. With pig-iron very strong contrasts can be made, but not so with wrought-iron. For photographic work the specimens must be more distinct and clearly marked than for mere microscopical work. The Author maintains that the photographs are perfectly easy and simple to obtain, and proceeds to describe with several illustrations the apparatus used in the Berlin Royal Experimental Institute.

In order to obtain a uniformity in the exposure, the Author takes several trial- or test-proofs, systematically increasing the length of exposure with each plate; he then selects the best proof, and gives all the following photographs the same exposure as indicated by the test photograph. The developing is treated in a similar way; and by this means the Author brings the process down to an almost entirely mechanical process.

Dr. Wedding was of opinion that sooner or later the microscope would become as indispensable as the testing-machine had become, and that all well-equipped laboratories and iron works would in time possess the necessary apparatus for microscopical research.

L. S. R.

Steel Casing for Blast-Furnace Hearth. By — Boivin.

(Comptes-rendus de la Société de l'Industrie Minérale, 1892, p. 73.)

The Author, after a general discussion of the materials used in the construction of blast-furnace hearths, and their susceptibility to corrosion when rapidly driven, describes a new form of hearth-casing adopted at Firminy. The hearth of this furnace, which is 1·80 metre inside diameter, has a wall 90 centimetres thick, made up of 25 centimetres of inside brickwork, a middle rammed lining of 50 centimetres, and an outside casing 15 centimetres of cast-steel. The latter is 2·6 metres high from the bottom of the boshes to the ground, about one-half of it being below the lever of the hearth-bottom, and is built up in rings formed of segments somewhat like those of a pit-tubbing. The rings are not complete circles, a space of 70 centimetres formed by two upright pillars being left on the tap-hole side, which is filled with refractory materials to allow the tapping-level to be varied if necessary. The segments made of annealed cast-steel are 1 metre long, 48 centimetres high, and 15 centimetres thick; their average weight is about 10 cwt., each one having, a perforated lug projecting in the centre for convenience of handling. When built up, they are in contact on the inside to a depth of 40 millimetres, the outer edges being shaped to form a groove of 30 millimetres maximum width, which is filled with clay, covered with a packing of asbestos, clamped by the flat side of a piece of iron tee-bar covering the joint The separate segments are connected by wrought-iron rings, which

rest in grooves of a corresponding shape, formed in the sides and corners of the plates; the whole structure being further strengthened by outside hoops connected to the upright pillars. The weight of the casing is about 27 tons. It is cooled by water constantly flowing over the outside.

The furnace was lighted on the evening of November 20, 1891, and in the first hundred days' blowing, made 8,004 tons of pig-iron and about 70 per cent. of that weight of cinder, or a total of 13,600 tons of molten material, or 136 tons per day. For about a fortnight, the make rose to between 100 and 107 tons, with 80 per cent. of cinder, or 180 to 190 tons melted per day.

Careful measurements have shown that there is no distortion in the shape of the casing, but judging from the large volume of material run from the hearth, the interior lining has to a great extent disappeared. From 30 to 33 tons of metal, and 5 or 6 tons of cinder, are considered as a minimum quantity at each tapping.

H. B.

Mineral, Metallurgical, and Industrial Chili.

By C. Vattier.

(Mémoires de la Société des Ingénieurs Civils, Paris, July 1892, pp. 37–140.)

The object with which this Paper is written is to draw the attention of French engineers, and of others interested in the extension of French industry, to the large field for their energy which exists in Chili, which of all the South American Republics is the most enlightened, the most honest, and the most liberal protector of industrial undertakings. The climate is healthy; hot and dry in the north, temperate in the centre, and wet, but never very cold, in the south. The labouring classes are brave, intelligent, and first-rate workmen in mining and metallurgical operations, in which last they compete on equal terms with the best European artizans.

Frenchmen already occupy many important posts, chiefly in the schools of medicine, of architecture, of arts and handicrafts, of agriculture, &c., but the commerce and industry of the country when conducted by foreigners are mostly in the hands of Englishmen and Germans. One of its most important industries consists in the production of nitrate of soda, in the province of Tarapaca, the export duty on which produces to the Government an annual revenue exceeding £2,500,000. The works are owned chiefly by Englishmen, some few by Germans and Italians, but hardly any by Frenchmen or Chilians. They are situated on elevated plains, of which the centre is at about forty miles from the Port of Iquique. The raw nitrate of soda yields from 20 to 40 per cent. of pure saltpetre, which is separated from the earth by boiling it under pressure, and many works have been erected on a vast and

costly scale for extracting and refining it.[1] There are also various establishments for the manufacture of Roman cement, beet-root sugar, beer, potato- and grain-spirit, ice, aerated waters, gunpowder, rope, cloth, coarse paper, lucifer matches, &c., and at Santiago, Valparaiso, Caldera, and Carrizal there are large foundries and workshops in which pumps, boilers, and even (at Valparaiso) railway locomotives have been constructed.

Geologically, the country may be divided into three regions, with two ranges of mountains, or *Cordilleras*, viz., the Western, or Maritime Cordillera, and the more elevated Andes. Granites, syenites, and other crystallised rocks are met with in the western range of mountains which forms the first region, and it is here that the most important copper and gold mines are found. Eastward of this range is the second geological region, which consists of stratified rocks of different ages, among which are jurassic limestones and clays, rich in fossils, and gypsum and barytes, resting in some places on metamorphic rocks and in some on other stratified rocks. Here are found iron and manganese ores, and the richest silver mines, such as those of Caracoles and Chanarcillo. Further to the east lies the third region, which extends partly up the slopes of the Andes; the rocks consist of conglomerates, porphyries, and schists, and contain iron and manganese ores, rich sulphates of copper (as at Los Condes, in the province of Santiago), and other minerals.

Gold is met with in many parts of Chili, but has not been worked on a large scale. At Guanoco, in the department of Taltal, very fine specimens are found in a matrix of quartz and sulphate of baryta, which is often transparent, and a good deal of gold is raised and exported. There are also mines worked in the provinces of Copiapo, Coquimbo, and Santiago; the value of the gold exported in 1890 was about £90,000.

The silver mines are much more important. Near Iquique, at a few miles from the sea coast, rich silver ore is raised at the mine of Huantajaya, and the mines of Caracoles, on the line of railway from Antofagasta to Bolivia, have produced enormous quantities of rich silver ore since their discovery in 1869. There are other important mines at Los Condes, Cachinal, Chanarcillo, Tres Puntas, Chanaral, and some in the provinces of Copiapo, Huasco, Vallenar, and Coquimbo. Bar silver of the value of £993,449 and silver ore of the value of £69,351 were exported in 1889, and besides this a considerable amount of silver was sold to the Mint at Santiago.

Above all, their copper mines for a long period formed the principal mineral wealth of Chili. Forty years ago Chili supplied one-third of the world's yield of copper, and until a few years since the annual produce was 40,000 tons, but this has now fallen to about 22,000 tons, while it is estimated that the rest of the world will produce upwards of 300,000 tons in 1892. It was

[1] Minutes of Proceedings Inst. C.E., vol. lxxxii. p. 337.

customary until about fifty years ago to work only such mines as produced native copper and copper oxides, carbonates and oxychlorides (*atacamite*), and when, at a certain depth, copper sulphides (pyrites) were met with, they were thrown aside because they could not be smelted in the small furnaces which were at that time used. But in 1840 a French engineer, Mr. Lambert, showed the people how to treat copper pyrites. He acquired mines in the province of Coquimbo, which is now the principal centre of copper production, and founded a wealthy family, now English. These pyrites contain only 3 per cent. to 4 per cent. of copper, while the average yield in Chili is from 12 to 14 per cent. The ores richest in copper are those of San Augustin, Los Bronces, Rio Blanco, &c., near to the rich silver mines of Los Condes, north-east of Santiago, and they contain from 20 to 25 per cent. of copper; but the great elevation of this district above the sea renders it impossible to work the mines for more than seven or eight months of the year. Other rich copper mines, far too numerous to particularise, are met with throughout the country.

Iron ores are met with in great abundance, and the Author earnestly impresses on his countrymen the advantage they might derive from being the first to establish blast-furnaces near to the immense virgin forests in the south of Chili, for the purpose of producing and also exporting charcoal iron. Lignite of good quality, in beds of from 2 to 5 feet in thickness, is found in abundance in the province of Bio-Bio, not far from the sea-coast, at Lota, Coronel, Arauco, and Labu; about 600,000 tons are now raised annually, and the production is rapidly increasing. Manganese ore containing 56 per cent. of peroxide and 24 per cent. of protoxide is now exported to England and to the United States on a considerable scale.

The several systems on which the mines are worked, and the ores enriched by washing and selection, and finally roasted and fused, are described at great length in the Paper. Copper ores of 3 or 4 per cent. are usually raised by such means to 16 or 18 per cent., and sometimes, as at Invernada, near Tiltil, to from 45 to 50 per cent. When roasting the copper ores it is important to be able to mix oxides and sulphides together, by which means, as at Lota, in the province of Illapel, a regulus is obtained at a single roasting, containing 50 per cent. of copper. The ores are smelted sometimes with wood, but more often with lignite, or foreign coal, and usually in reverberatory furnaces similar to those used at Swansea; but in some parts of the country blast-furnaces are preferred. They are cheaper to construct, and a greater quantity of ore can be treated in them at one fusion, 40, 50, and even sometimes as much as 60 tons being fused in twenty-four hours.

In the treatment of silver ores containing less than 10 per cent. of lead, a system of amalgamation was introduced in 1862 by the late Mr. Hertzog, and further improved by Mr. Kronke, by whose name it is now known, which, in the opinion of the Author, is

very superior to the processes employed either in the United States or in Europe. A sub-chloride of copper is prepared by dissolving together in wooden casks some sulphate of copper and salt, adding thereto some leaves of metallic copper, steam being then admitted until the whole has acquired a green appearance. From 3 to 5 tons of finely ground silver ore having been charged into a large wooden vat, 7 feet in diameter, a hot salt solution and some of the chloride of copper preparation (varying in quantity according to the nature of the silver ore) are added to it. The vat is then made to revolve, at first slowly, until the whole is well mixed together, when some mercury and an amalgam of zinc, with the addition of more water, and sometimes of a little sodium, are introduced into the mass and thoroughly mixed with it. After this the vat is again revolved more rapidly during six or eight hours. The greater part of the mercury and amalgam is then allowed to collect at the bottom of the vat, and the rest is poured into a vertical wooden pug-mill, and again stirred up. The liquid mud is made to run from this over a winding, inclined, and slightly corrugated floor, more water being added until the matrix has been exhausted; the mercury and amalgam are collected and washed, filtered, pressed, and distilled in the usual way. Two operations are performed in twenty-four hours, and this system of amalgamation is much more economical than the fusion of the ores.

Mines of mercury, of cobalt, and of nickel are met with, but only worked on a small scale.

O. C. D. R.

On Copper-Smelting in Russia. By — Weiss.

(Annales des Mines, vol. ii. 1892, p. 285.)

The production of copper in the Russian empire during the decennial period 1881–90, has varied between 3,515 and 5,824 metric tons per annum, the amount being contributed in nearly equal proportions by the mines of the Ural and the Caucasus, the districts of the Altai and Finland having only a small output of about 300 tons each, while the Kirghese mines, which were formerly of some importance, being situated in a desert region depending upon camels for transport, have latterly been almost entirely abandoned. The Author has therefore confined his description to the more important centres of Bogoslovsk and Tagilsk in the Ural, and Kedabek in the Caucasus.

Bogoslovsk Works.—These works, purchased from the Crown by the present proprietor, Mr. Polovtzof, about ten years since, are about 160 miles north of Kouchva, on the Perm and Tiumen Railway, and about 4 miles from the mines, with which they are connected by a narrow-gauge railway extending about 35 miles further to the Sorva river, whence the metal is sent by water to

the railway terminus at Tiumen. The situation being such as to prevent the use of the inferior coal produced in the Ural, the works are dependent for fuel on the forests belonging to the estate. The trees cut in the autumn are drawn over the snow in sledges to the banks of the numerous watercourses, whence the spring flood brings them within reach of the smelting establishment.

The ore treated is copper pyrites, containing between 4 and 5 per cent. of copper, the yield having diminished progressively from 10·09 per cent. in 1881 to 5·28 per cent. in 1887. The output of the two principal mines in 1890 was 39,222 tons, giving 26,188 tons of selected ore by hand-picking, and 24,466 tons after calcining at the mine. The smelting process formerly used consisted in running the burnt ore in a low blast-furnace into coarse metal, which was roasted in heaps several different times and converted into blister copper in the spleissofen, a reverberatory furnace with a circular bed and domed roof. The refining and toughening of the blister copper was done in a reverberatory furnace.

Since the change of ownership, 1881, considerable alterations have been made by Mr. Auerbach, the manager, by the introduction of a second fusion for white metal of 60 per cent., and more particularly in the use of the Bessemer converter for the production of blister copper. The experiments with the latter have been very successful, and in 1890, 745 tons of blister copper were made by it, and only 717 tons by the older process. The difference would have been still greater if the present plant of eight converters had been equal to treating a larger quantity of material. The converters adopted by Mr. Auerbach differ from those of Mr. Manhès in the position of the twyers, which are placed at an angle of 45 degrees to the lining, instead of being horizontal. Thus the risks of oxidizing copper by blowing through the metal and of cooling the charge by blowing through the slag are both avoided, the twyer orifice being placed at the level of the plane of separation of metal and slag. Owing to the corrosive action of white metal upon the lining, the consumption of refractory materials was at first very large, and added considerably to the cost of the operation, but it has since been found that common brick-earth, such as is found adjoining the works, stands wear equally well with the best siliceous brick, and the use of the latter has consequently been abandoned. The bottoms require to be replaced after nine or ten blows, and complete relining is required about once in three months. The blowing-engine, driven by a turbine, supplies blast at a pressure of 25 to 30 centimetres of mercury, or 5 to 6 lbs. per square inch.

The eight converters in the Bessemer shop are arranged in two groups of four, each group having two reverberatory smelting furnaces. When in use one converter is blowing, a second is under repair, a third is cooling, and the fourth warming up. The operation is performed in two stages; in the first the coarse metal, by

the elimination of sulphur and iron, is reduced to fine metal, and the second the sulphur in the latter is oxidized, bringing it to the state of blister copper. In the first operation 32 cwt. of coarse metal, with 20 per cent. of copper, melted in a reverberatory furnace is run into the converter and blown for 25 or 30 minutes. By the burning of the sulphur and iron the temperature rises rapidly, and a yellow flame, with violet edges and filled with very bright sparks, issues from the mouth of the converter. As the iron decreases the flame drops, and finally becomes green, when the operation is finished and the charge is poured into moulds, where the slag and regulus separate in cooling. The latter averages about 64 per cent. of copper.

In the second operation the white metal of the first blowing is remelted and blown to blister copper; this requires a longer time and is less easily effected than the first conversion, as the only combustible constituent, sulphur, gives such a small amount of heat that there is danger of the charge setting. It is, therefore, necessary at times to raise the temperature by throwing in charcoal, and two men are continually engaged in keeping the twyers open with iron prickers. The blow lasts from one to one and a-half hour, and is considered to be finished when no unchanged regulus is found in the projections, collected on a shovel inserted into the converter. The flame, which is at first green, changes at the end to a reddish-yellow. The slags, containing 5 to 6 per cent. of copper, are poured out first, and afterwards the blister copper, which is refined in the reverberatory furnace in the usual way.

In the same converter three or four consecutive blows for white metal are followed by two for blister copper, and two or three more for white metal, the object of the alternation being to remove any masses of copper adhering to the lining. The average assay of the blister copper from the converter is 96 per cent. In 1890, 5,013 tons of 19 per cent. coarse metal were converted in 3,825 blows into 1,549 tons of white metal, and the latter by 887 blows into 746 tons of blister copper. The total weight of slags produced was:—

	Tons.	Containing Copper
		Per cent.
No. 1. In the melting-furnace	338	10·2
No. 2. In the first (white metal converter) . . .	960	1·8
No. 3. In the second (blister copper converter) . .	383	5·7
Converter fume	64	14·7

The cost of each Bessemer blow is given at 7·86 roubles, and of refined copper 0·43 rouble per kilogram.

A small plant for the production of electrolytic copper, driven by the surplus power of the works, was under construction at the time of the Author's visit. This it was thought could be advantageously operated, owing to the circumstance that the copper can only be sent away once in the year, and therefore the keeping of a large stock of materials in the anodes and kathodes will be less

prejudicial than it is in establishments which are in constant communication with their market. The copper also contains about 13 ozs. of silver per ton, and traces of gold which would be recovered by electrolysis.

Nischne Tagil Works.—These works, belonging to Prince Demidoff, are now of considerably less importance than formerly, the production of copper which was 3,305 tons in 1852 having diminished to 700 tons in 1890. The ores, mixed oxides, carbonates and sulphides contain from 2 to 4 per cent. of copper, having decreased considerably in value with increased depth in the mines. They are smelted for coarse metal, which is burnt in five or six fires and smelted for black copper and rich regulus, the refining being done in a reverberatory furnace. There are six blast-furnaces with fore-hearths for ore-smelting with coke, of 16 tons capacity per twenty-four hours, a water-jacket furnace for smelting calcined pyrites, eight smaller charcoal furnaces for the second metal fusion, two refining-furnaces, and a wet extraction plant. The only point of interest is the Herreshoff water-jacket, with movable fore-hearth, which has been in use since 1888, but without very satisfactory results, as it has been found difficult to keep the water-cooled joint between the furnace and the receiver from enlarging by corrosion. The materials smelted in this furnace are pyritic ores burnt in heaps, with 20 or 25 per cent. of rich slags and 10 to 15 of argillaceous ores; about 50 tons are smelted per day with 5 cwt. of coke per ton. The blast, at a pressure of ½ inch of mercury, is supplied by three 2-inch twyers. About 22 gallons of cooling water are used per minute. The regulus contains from 25 to 30 per cent. of copper.

The ores, although of low produce, being very free from injurious substances, give copper of a high standard of purity, averaging only 0·003 to 0·0055 of iron, 0·031 to 0·036 of arsenic, and 0·07 to 0·08 of antimony per cent.

In August, 1891, the Hunt and Douglas process of extraction by sulphate of iron and salt was introduced for the treatment of the poorer ores containing 1·5 to 2·5 per cent., which cannot be beneficially smelted.

Mines and Works in the Caucasus.—Deposits of copper ores in the Caucasus are very numerous, but being for the most part in difficultly accessible places, without roads or fuel, few of them have as yet been worked to any extent. In 1888 there were ten works producing copper in the Caucasus from ores ranging from 5·7 to 12 per cent. produce, with a total return of about 1,500 tons, but none of these are of any great importance except those of Kedabek and Kalakent, belonging to Messrs. Siemens Brothers, which, together, yielded 1,113 tons of the total given above.

The mines and smelting works of Kedabek are 4,000 feet above and 33 miles south of Dalliar, on the Tiflis and Baku Railway, with which they are connected by a very bad cart road. There being no fuel or water-power available on the spot, a connection has been made with Kalakent on the Chamkor River by a narrow-

gauge railway 14 miles long, where wood and charcoal can be obtained from the Crown forests. As, however, the supply from these is strictly limited, the principal fuel used is mazut or the residual naphtha obtained in petroleum-refining, which is brought by railway from Baku and carted to the works, the cost being increased from 2·4 roubles at the refinery to 22·8 roubles at the smelting works. A pipe line made of Mannesmann tube, covering about half the distance from Dalliar to Kedabek, with a rise of about 2,600 feet, has been established, but was not at work during the Author's visit, the couplings of the pipes having burst under the pressure required for forcing the naphtha up hill. The cost of charcoal is about 15 roubles per ton, its heating power being considered to be about 28 per cent. of that of an equal weight of naphtha. The deposits, which are irregular masses of cupreous pyrites, quartz and diorites, yield three classes of ores, the first, or richest, containing pyrites with 15 to 24 per cent. of copper, about 5 per cent. of barytes, and 7 per cent. of blende, with a sub-class of oxidised minerals of very irregular composition, ranging up to 40 per cent. The second, or medium, class, which is numerically the most important, ranges from 5 to 12 per cent. of copper, averaging 7 to 8 per cent. with blende, barytes, and a considerable amount of iron pyrites. These ores are very friable, and always acid; they are mostly obtained in the form of sand. The third, or poor, class of minerals, containing less than 5 per cent., is reserved for treatment by the wet way. The yield of the mine in 1890 was 30,769 tons, giving 21,373 tons for smelting.

The poor ores with 2·5 to 5·0 per cent. of copper are separated by hand, the coarser pieces being burnt in heaps and the smaller in four Gerstenhofer calciners, the gases from these being used to acidify the mine water employed in washing out the copper. The roasted minerals are arranged upon an asphalted floor in large rectangular heaps traversed by numerous horizontal and vertical channels, giving free circulation to the washing water which passes from one heap to another in regular order, and is received in wooden tanks containing scrap-iron. The precipitate copper is taken out at intervals, washed, and sent to the smelting works. About 1·2 ton of scrap-iron is required to produce 1 ton of 60 per cent. precipitate copper. The annual make is about 110 tons.

The ores being very pure the smelting treatment is comparatively simple, including two calcinations, two fusions for regulus, a fusion for blister copper and refining. The lump ores are calcined either in heaps or kilns; the latter are preferred as being most expeditious, the operation being completed in twenty-four hours. The smaller are treated in Gerstenhofer calciners, with twenty or twenty-two series of shelves heated by naphtha, which is consumed at the rate of about 3½ cwt. per furnace per day. These furnaces are extremely rapid and effective in work, and have entirely replaced the reverberatory calciners.

The fusion for coarse metal is to a great extent effected in a large circular furnace, with a domed roof heated by the flames of two naphtha burners, which pass over the bed in a horse-shoe shaped track, but at some distance from the sides, the heating being done by radiation from the flames and not by contact. Each burner has three orifices, the central one, 10 × 2 millimetres, supplying the naphtha, the bottom one, 20 × 1 millimetres, steam, and the top one, 30 × 6 millimetres, air. The flame passes to the chimney by a long inclined flue, which does duty as a calciner, the small ore being fed in at the upper end, and passing gradually downwards. Originally it was intended to drop the calcined ores into the furnace hot, but this has been given up on account of the temperature prevailing at the lower end of the flue, which is sufficiently high to melt the ore before it reaches the furnace. In the latest construction, a coil of air-heating pipes has been introduced into the flue in order to save some of the waste heat. About 38 tons of 7 per cent. small ore, with 2 tons of iron ore as flux, are smelted in twenty-four hours, with a consumption of 4 tons of naphtha. The coarse metal, which is tapped once in twenty-four hours, contains 23 per cent. of copper. The slags, which are very silicious (50 per cent. of silica), contain 0·25 per cent. of copper. The furnaces are very easily and economically worked, and when the pipe-line is in operation the small charcoal blast furnaces will be entirely superseded, but at present the latter are exclusively used for the second process. The refining-furnace is fired by naphtha, which is consumed at the rate of 24 cwt. for 8 tons of blister copper refined in twenty-four hours.

At the Kalakent Works a portion of the ore from Kedabek, carried as return freight by the empty charcoal trains, is smelted in low blast furnaces, and an electrolyzing plant, driven by water-power, has been established for the treatment of the poorer kinds containing not more than 4 per cent. of copper. These are ground in a Carr's disintegrator at the rate of 20 tons in twelve hours, and roasted in the Gerstenhofer calciner. The roasted ore is then subjected to a methodical washing with clean water in wooden vats containing 5 tons each, in order to remove the copper sulphate, and the solution obtained from the four vats in use is filtered by passing through four similar vats containing ore that has been previously washed, so that the last traces of copper may be removed. It is then slightly acidulated and passes to the electrolyzing vats which are arranged in cascade series, the liquor passing from one to another until it is completely exhausted. The anodes are plates of blister copper and the kathodes thin sheets of pure copper. The current of 400 amperes and 20 volts is furnished by a Siemens and Halske dynamo taking 30 HP. In 1890 the production of electrolytic copper was 81 tons.

When the works were started in 1887, anodes made of a mixture of charcoal powder and clay moulded under pressure and strongly heated were tried, but without success, on account of the

excessive polarization. Since that time, the new Siemens method of preventing polarization by forming ferric sulphate in the bath has been developed, but it had not been introduced at Kalakent in 1891. The Author concludes with an account of the new process, which is similar to that previously published.[1] There are numerous details as to the cost of copper at the different works, but as these are given in Russian currency without indicating the rate of exchange they are not reproduced.

H. B.

Method of Coppering Ships by Deposition.

(Railway Review, Chicago, September 17, 1892, p. 579.)

A method of coppering ships' bottoms by electro-plating has been practically introduced by an American inventor. The vessel is docked and her skin cleaned with the help of a dilute acid which is applied by means of a water-tight bag of canvas and wire, and large enough to envelop the hull. After the surface of the metal is cleaned, the acid is withdrawn and its place taken by a solution of copper-sulphate, electric currents being sent through the solution from a dynamo. In this process the hull of the ship forms the kathode, and the metal of the containing-bag the anode. The solution of copper-sulphate is thus decomposed, and a layer of pure copper is deposited on the iron. The shell of copper can be of any required thickness, and it can be renewed. The process has been tried with success in a vessel in New York Harbour.

F. G. D.

Cellulose, and its Application as a Protection to Vessels.

By J. M. Cheneau.

(Proceedings of the United States Naval Institute, 1892, p. 221.)

The idea of protecting vessels by means of a very light self-obturating material was conceived by Admiral Pallu de la Barriere, an officer in the French Navy. The material proposed by him for this purpose, and known as cellulose, exists in all plants and in the tissues of certain animals of the lower order; the chemical formula representing it is $C_{12}H_{10}O_{10}$. If a fragment of wood is subjected to successive washings with cold or hot water, or weak alkaline, or acid solutions, until all soluble substances are removed, a fibrous or cellular material remains, which is in effect the skeleton of the plant—hence the name cellulose. The husk of the cocoa-nut contains a large proportion of cellulose in the form

[1] Minutes of Proceedings Inst. C.E., vol. cviii. p. 497.

of a species of pith which holds together the fibres surrounding the nut. This pith is not chemically pure cellulose, as it contains about 30 per cent. of the salts of potassium and sodium, traces of manganese, a great deal of tannin, and some salts of lead. The analysis of cellulose made from cocoanut-husks is as follows :—

	Parts.
Pure cellulose	83
Organic extracts	10
Ashes	7
	100

The presence of these salts and the tannin secures the substance from decay and the attacks of insects. The weight is one-fourth that of cork; it is very compressible and elastic; it absorbs water rapidly by capillarity, and swells up on account of this absorption. It is employed for the protection of vessels in two ways :—

(1) In the form of a belt at the water-line 5 or 6 feet in thickness, composed of 14 parts by weight of cellulose in a granulated state mixed with 1 part of the fibre or filamentary part of the husk of the nut. This mixture is placed in cofferdams or watertight divisions and compressed to one-half its original volume. The elasticity of the material causes it to close up after the passage of a projectile and effect an instantaneous obturation; the water attempting to follow the projectile causes the material to swell, with the result that the admission of water in any quantity is effectually checked.

(2) In the form of water-excluding briquettes, occupying spaces not utilized in the vessel and preventing the admission of water. For this purpose the briquettes are enveloped in a water-proof covering to prevent absorption of water and consequent increase of weight. The material is extensively used in the French navy, and several countries have adopted it. It is now being manufactured in America for the use of the United States navy.

S. W. B.

A 500-HP. Dynamo. By E. Dieudonné.

(Bulletin de l'Association des Ingénieurs sortes de l'Ecole de Liége, 1892, p 129.)

In this article the Author gives particulars of an electric generator of 500 HP., which has been installed in a small-arm factory near Liége,[1] for the purpose of distributing power to the various machine-tools throughout the works. The machine is coupled direct to a Van der Kershove engine running at 66 revolutions per minute. The output is 2,400 amperes at 125 volts. The armature is of the Gramme type, 15 feet 9 inches in

[1] *Post*, p. 511.

diameter, the radial depth of the core-plates being $5\frac{1}{8}$ inches, and the length of core 16 inches. The core is built up in the usual manner, of segmental sheets 28 millimetres thick. It is wound with two independent circuits, each containing 1,200 turns of wire, and provided with a commutator 3 feet 3 inches in diameter, one on each side of the armature. The field is formed by a crown of cast-steel magnets surrounding the armature. There are twenty poles arranged in ten castings. Each casting has two poles and two exciting coils, and the successive castings are bolted together by flanges. The density of current in the exciting wire is 1,000 amperes, and that in the armature wire is 1,900 amperes per square inch. The weights of the different parts are given as follows:—

	Tons.
Field-magnet castings	10
Armature-core	6
Centre of armature	8
Magnet-wire	1
Armature-wire	0·6

The clearance between the armature and polar faces is 0·237 inch.

G. K.

High-Pressure Dynamos coupled in Series. By E. Meylan.

(L'Électricien, 1892, p. 94.)

Pontresina is lighted by power carried electrically from the Bernine Fall to the town, in the shape of a continuous current of 34 amperes, and at a voltage which may be either 1,500, 3,000, or 4,500 volts, accordingly as one, two, or three generators are coupled in series. The Author describes the method of bringing machines into or out of circuit. Suppose that at the generating-station only one dynamo is at work, and that, owing to increase of load, and, consequently, increase of current beyond 34 amperes, it becomes necessary to add the second machine. The attendant signals down to the sub-station in Pontresina that he will insert another machine, and thus raise the voltage from 1,500 to 3,000. The second machine is ordinarily short-circuited on the switch-board, and by the insertion of resistances this short circuit is gradually withdrawn. The current from the first generator is thus gradually sent through the second generator whilst the latter remains at rest, it being mechanically locked so that it cannot turn backward as a motor, which would otherwise be the case. Water is then gradually admitted to the turbine of the second machine, the locking device thrown out of gear, and the machine is gradually started. The voltage at the generating-station is thus slowly raised from 1,500 to 3,000 volts. Meanwhile the attendant at the sub-station, who has been warned by the signal, must insert a second of the continuous-current transformers. If

this were inserted in the same way by opening the short circuit on the switch-board, it would immediately start off with the full torque, and thus reduce the speed of transformer No. 1. To avoid this the field winding is subdivided into six sections, and these are inserted one by one by means of a suitable switch, with the result that the second transformer starts very slowly, the attendant regulating the increase of speed in accordance with the indications of the voltmeter, and when the full pressure and full speed are reached, he throws the low-pressure winding on the transformer into parallel with that of the first transformer. This completes the operation. The Author states that, although this method of coupling up is somewhat complicated and requires care, it is daily used with perfect success.

G. K.

The Efficiency of the Electrical Transmissions of Power at Frankfort.

(Elektrotechnische Zeitschrift, 1892, p. 345.)

The results of the tests made by the Special Commission at the Frankfort Exhibition of 1891 for the purpose of finding the efficiency of the electrical transmissions of power at Frankfort are given in the following Tables. The work of the Commission may be divided into three parts; the first was the power transmission carried out by the Allgemeine Elektricitäts Gesellschaft of Berlin, in conjunction with the Oerlikon Works, near Zurich, by which about 300 HP. produced by water at Lauffen was transmitted 108·5 miles to Frankfort-on-the-Maine. The results are given in a Table, and were obtained from seventeen tests, each of ten minutes' duration, made from October 11th to October 15th, 1891, inclusive. The average of all the tests was as follows:—

HP. of Turbine.	Electric HP. of Dynamo.	Percentage Efficiency of Dynamo.	Electric HP. given out by First Transformer.	Percentage Efficiency of First Transformer.	HP. lost in leads.	Electric HP. delivered to Second Transformer.	Electric HP. given out by Second Transformer.	Efficiency of Second Transformer.	Efficiency of the Transmission.	
									Between Dynamo Terminals and point of Consumption.	Between Turbine Shaft and point of Consumption.
140·1	127·5	90·0	121·4	95·0	12·6	120·5	103·0	94·4	81·0	73·3

The efficiency of 73·3 per cent. is therefore the energy actually consumed in the lamps at Frankfort compared with the energy actually given out by the turbine-shaft at Lauffen. Other results

obtained at Lauffen as to the behaviour of the plant at from 25,000 to 30,000 volts will be given in the Exhibition report.

The second series of tests was made upon a plant shown by Messrs. Garbe, Lahmeyer & Co., which consisted of a 20-HP. portable engine in the Palmgarten, which drove a dynamo producing high tension direct-current. This current was taken to the Exhibition, a distance of 1·24 mile, and there drove a motor.

Generating Station.				Motor Station.						
Volts at Dynamo.	Current in Amperes of Dynamo.	Total Watts transmitted.	Revolutions per Minute of Dynamo.	Potential at Motor.	Current at Motor.	Watts delivered to Motor.	Revolutions of Motor per Minute.	Brake HP. of Motor.	Percentage Efficiency of Motor.	Percentage combined efficiency of Plant.
1,107	13·95	15,442	511	1,045·0	13·95	14,578	370	17·44	88·10	83·10

The above results are those of one test only. The results of nine tests are given; but, as the electromotive force at the dynamo varied from 1,124 to 194 volts, they are not averaged. The highest combined efficiency obtained was 84·70 per cent. with 977 volts, and the lowest 81·40 per cent. with 970 volts.

The resistance of the mains was 5·9 megohms (*sic*). The third part of the tests consisted of similar arrangements upon a power transmission by electricity from Offenbach by Messrs. Lahmeyer & Co., of that town. The details of these tests are not as yet worked out, and will be given in the official report of the Exhibition.

E. R. D.

Historical Development of the Main Overhead Telegraph Lines in Prussia. By — Noebels.

(Archiv für Post und Telegraphie, 1892, p. 409. 76 Figs.)

The Author states that the first telegraph line in Prussia was made in 1848, and that both overhead and underground construction was used. This line from Berlin to Aachen itself replaced the semaphore telegraph from Berlin to Trèves, and was overhead from Berlin to Potsdam and the rest underground. Also that from Berlin to Frankfort-on-Maine was overhead between Berlin and Eisenach, and the rest underground. The underground work was very unsatisfactory, and the vulcanized gutta-percha insulation was useless. The sulphur formed sulphate of copper, and with the gutta-percha caused earth connection. All this work was replaced in 1852 by overhead lines.

The Author divides his subject under four heads:—Leads, nsulators, posts, and cross-bars.

Round copper wire was at first used in all cases, and the diameter was specified as 0·064 inch, to allow the batteries to be placed 50 or 60 miles apart. This size was found mechanically defective, and the diameter was raised to 0·086 inch, and finally to 0·094 inch. The weight alone of the wire caused it to stretch in warm weather, the different wires became entangled owing to the great sag, and if tightened up they broke in winter. The posts had therefore to be placed not more than 27·2 yards apart, and the insulators being imperfect great loss to earth took place.

It was so unsatisfactory that in 1852 the Prussian authorities substituted iron wire 0·18 to 0·19 inch in diameter. While the price of copper per mile had been £42, that of iron was only £27, and the complete line, with posts and insulators, now cost £55 instead of £180. The objection to iron wire was its liability to rust, especially when near railway stations and manufactories. At first it was coated with asphalt; but this was unsatisfactory, and linseed oil varnish was used up till 1873. The process of galvanization was brought out by a Frenchman named Sorel, and in the fifties had little success, as the coating was liable to peel off. In 1854 a prize was offered for the best method of galvanization, and, in order to test its quality, it was to be used for one year on the telegraph lines; the cost of the process was not to raise the price of the wire more than 11*s.* 6*d.* per cwt.

Satisfactory galvanized wire was obtained in 1855. In 1857 the cast-iron bells previously used were replaced by insulators entirely of porcelain, and the diameter of the wire was reduced to 0·146 inch; but this increased the resistance too much, and 0·157 inch diameter wire was afterwards used until 1868. For international lines, until 1868, wire of at least 0·196 inch diameter was used; the North German lines used 0·21 inch diameter; the larger diameter of 0·235 inch was only used for the Indo-European line from Ems to Thorn. Since 1873 galvanized wire only has been used. The Author states that at present the sizes are 0·196, 0·156, 0·117, 0·098, and 0·078, the last for binding wire, and 0·067 inch for jointing-wire. In particular places galvanized steel wire is used—as for example in crossing the Rhine at Bingerbrück, where three wires, each 0·118 inch diameter, are used for the span of 2,500 feet.

In 1880 the Government Telegraph Department took up telephone work, and used galvanized steel wire 0·086 inch diameter, with a breaking load of 1,200 lbs. on a length of 5·8 inches, as it presents less surface for the wind than iron wire of equal strength. Experiments recently made with hard-drawn copper and steel coated with copper have not been successful, and silicon-bronze has been found to give the best results, but costs 1*s.* 4*d.* to 1*s.* 10*d.* per lb. After the good results obtained in the Lauffen-Frankfort transmission this wire came into greater use.

The Conference at Paris in 1890 settled that the resistance of international wires should be, as a maximum, 12 ohms per mile; but left the choice of material to the local authority. Instead of

galvanized iron wire 0·196 inch diameter, with a resistance of 13·3 ohms per mile, silicon-bronze, 0·118 inch diameter and 4·5 ohms resistance, is now used. At the beginning of 1890 the new line from Berlin to Rome was made of the alloy, in order to obviate retransmission, and although the distance is 1,200 miles, the Hughes apparatus works perfectly. The Author then describes the various methods of jointing which have been in use; but the Britannia joint is now always employed. Drawings and descriptions are given of the various kinds of insulators which have been used. Some of the forms were too weak, and the wire came in contact with the metal support. Some of the early types had cast-iron bells supported on porcelain cups, which were carried by iron supports; the great disadvantage, however, was the possibility of damp entering the bell. Some alterations were made by Borggreve, which were unsuccessful, as 30 per cent. of the insulators burst per annum. The Chief of the Telegraph Department, Mr. Von Heydt, therefore nominated a commission in 1857 to study the question, and they recommended glass as the material, but this proved too brittle. After this Von Chauvin brought out his double bell insulator, and this was carefully tested upon the Berlin-Magdeburg-Cologne line in competition with two other kinds, and proved very superior. Since 1862 this type alone has been used, and three sizes are employed which are illustrated. A thread is formed on the inside where the support enters, and the fixing is effected by wrapping hemp dipped in linseed-oil round the notched support and screwing it into the bell. Other forms of insulator are shown which have been used upon growing trees. Hook-formed supports, screwed direct into the posts, were used; but were at first unsatisfactory, as the part inside the bell was square and caused it to burst; this was afterwards made round, and now gives satisfactory results. Pendulous insulators are in use where the wires are attached to trees.

Wooden cross-arms have long been given up, and iron only is used. For the posts the most suitable wood was found to be Scotch fir (*Pinus Sylvestris*), and these at first were barked only, but are now planed also.

For railways these posts must be 16 feet long, and at crossings 26 feet, while for roads, posts 25 feet long are always used. At first the trees were used with the sap in, and only charred at the bottom; then a coat of asphalt was tried, with poor results. Various compounds of sulphur were then caused to enter the posts by pressure; but no success was attained, and they soon rotted.

Chloride of zinc in solution was at that time found best, and upon a line 14 miles long all the posts lasted five years, and at the end of sixteen years 44 per cent. were still in use. In order to be able to use posts which had rotted in the ground, cast-iron feet were let into the ground and the upper ends were let into the posts; in other cases, screw piles were put in and the post clamped to the top.

It was found that the true cause of rotting was the presence of the sap in the wood. The posts were dried by heat; but this

deteriorated their elasticity, and the only method found practicable was impregnation with metallic salts or tar.

The Author then describes the copper sulphate process of Boucherie, the creosote process of Bethell, and the mercury chloride process of Kyan.

The Boucherie process was first used in Prussia in 1858, and proved very satisfactory, as the posts last ten to fourteen years. Treated by the creosote process, they last fifteen to twenty years; but it is much more expensive. For these reasons the Boucherie process has been used alone since 1873.

To protect the top of the posts many methods were tried and are described. That now in use consists of cutting them to a roof shape and coating them twice with tar, and adding sand to the latter coat while wet. The difficulty of obtaining good posts led to the adoption of iron; the first were made in 1855, and consisted of wrought-iron tubes on cast-iron bases. Granite bases with wrought-iron posts were used in some cases, but were not satisfactory; and tubular posts were also made and filled with concrete; but these all broke in gales, whereas the wooden posts were uninjured. Wrought-iron of H section let into stone bases was also tried recently, but was found impracticable.

It has been proved that iron posts are only of use for light lines, and the posts must be short and close together, making the cost excessive.

In recent years, owing to the increased traffic, treble posts have been made, provided with cross angle-irons, upon which are fixed the insulators; this has the advantage that posts can be replaced without taking down the insulators.

E. R. D.

The Municipal Supply of Electricity at Cologne.

By F. Uppenborn.

(Elektrotechnische Zeitschrift, 1892, p. 351. 24 Figs.)

The Author went on the invitation of the Helios Company to examine the municipal supply station for electricity at Cologne. The Director of the Town Gas and Waterworks was asked to report to the Town Council upon the best scheme, and he chose that of alternate current with transformers. On February 13, 1890, the Council voted £92,500 for the purpose of creating a central station. The boilers are by Steinmüller of Gummersbach, the engines by Sulzer of Winterthur, and the electrical apparatus by the Helios Company of Ehrenfeld. Building was begun in April, 1890, and on September 10, 1891, current was first delivered to the Volksgarten. The station is on the outskirts of the town, near the Bonner Thor, and the whole can be lighted, but at present the

area supplied is in the centre of the town. The distance from the station to the area lighted is about 2,000 yards.

The system of supply is by a high-tension network feeding transformers, placed either in the building supplied or in a small sub-station which supplies several neighbouring buildings; the high-tension mains are so designed that the loss of potential may be neglected, and no regulation is as yet needed at the central station. The Helios transformers only show a difference of 2 per cent. between full and no load, and in the distributing network at full load there is a loss of only 5 per cent. In the house connections a loss of 1 volt is allowed, and the working pressure is 72 volts. The feeders are designed for 20,000 lamps, and with 72 volts at the consumer's terminals, the pressure at the station fluctuates between 72·75 and 73 volts. The transformers are designed for small loss in the copper and greater loss in the iron.

The figures show a plan and elevation of the station, from which it appears that there are two principal rooms, the engine and boiler houses, each 150 feet long and 52·5 feet and 42·5 feet wide respectively, and a number of smaller rooms which serve for feed-water purification, repairs, mess-room, and offices. There are six boilers of the Steinmüller type, with 2,270 square feet of heating-surface each, and working at a pressure of 150 lbs. per square inch. These boilers supply steam to the municipal pumping-station, and a regular supply of steam is required all the year round, as the maximum output of electricity is in the winter and of water in the summer; the same applies to the day loads, as light is required in the evening and water during the day.

The Author states that the waterworks boiler-plant is now disused, and that the amalgamation of water- and electricity-works is quite a novel idea. Details are given as to the number and dimension of tubes, &c. Two water-purifiers of the Froitzheim type are used, and are fed either wholly from the water-mains or partly from the condensers. Each has an output of 1,100 gallons per hour, works continuously, is fitted with a Körting steam-mixer, and deposits a quantity of chemicals proportional to the flow of the water. The purified water flows to the feed-tank and is drawn out by the feed-pumps, of which details are given. The steam from the boilers passes into two welded wrought-iron pipes 12 inches outside diameter and 0·295-inch thick; each of these pipes can be connected to the existing boiler-plant at the waterworks, so that if needed the two sets could be used together. The space between the outer wall of the boiler-house and the setting of the boilers, is arched over and used as a reservoir for the feed-water; it has a capacity of 110,000 gallons. In this way the purification goes on continuously, while a large demand can be made temporarily on the supply by the boilers.

The chimney is 164 feet high and 8·2 feet diameter. In the engine-house are placed two compound horizontal condensing engines by Sulzer, the high- and low-pressure cylinders of which are respectively 25·5 inches and 37·5 inches diameter, and the

stroke 49 inches. When running at 85 revolutions per minute, with an initial pressure of 82 lbs. per square inch and a cut-off of 22 per cent. and 38 per cent. in the high-pressure cylinder, the I.HP. was 590 and 570 respectively, and the B.HP. 500 and 650 respectively; a third similar engine will be erected in September, 1892. For the supply at the hours of small demand, a single-cylinder condensing engine is provided; its diameter is 17·6 inches and stroke 35·5 inches, and it develops 125 to 150 B.HP. at 85 revolutions per minute, with 82 lbs. pressure per square inch. Arrangements are so made that this engine can be replaced by a large one if necessary.

The cold water used for the condensers flows from the reservoir, and the warm water passes into a tank which overflows into a canal. The engines can if required be worked non-condensing.

Each cylinder drives a crank placed at the end of a common horizontal shaft, and the alternator with its exciter is placed between the bearings. The field-magnets are attached to a revolving drum which acts as a fly-wheel; it is 14 feet diameter and carries 72 poles, at 85 revolutions per minute there are, therefore, 102 alternations per second; this magnet-wheel can be drawn out sideways to allow of examination. The armature is stationary, and consists of a ring of 72 coils, each insulated from the frame and neighbouring coils. The potential between the terminals is 2,000 to 2,500 volts, and the output of the large machines is 450 kilowatts, and of the small day load machine 90 kilowatts. All these machines work in parallel, and the exciter is placed upon the same shaft as the dynamo, and has 8 poles and develops 300 amperes at from 64 to 100 volts pressure; the energy spent on the exciter is 4·2 per cent. of the whole output.

An overhead crane capable of lifting 30 tons is placed in the engine-house. A platform about 10 feet above the floor is used for the controlling apparatus, and it is impossible to touch the high-tension leads during work as they are in a separate room. The instruments for each machine are placed on a pillar, and the four levers for working the switches are similar to railway signal levers. In each pillar is placed an amperemeter for the main current and also a volt- and ampere-meter for the exciting current. A small transformer is used with a voltmeter to show the pressure on the distributing mains, and lamps are used for synchronising the machines before throwing them into parallel.

The Author then enters into a detailed description of parallel working. At the hours of light load the small alternator works alone, and the chief work is the magnetization of the transformers, which at times reaches 20 per cent. of the output of the machine. A recording voltmeter is used, and when the station first began work, on switching in a second machine, fluctuations of 5 volts took place lasting one or two minutes; these have now been obviated, and the maximum fluctuation is 2 volts for a few seconds.

The total length of the network is about 12·4 miles. From the station pass out three main cables, each having a section of $2 \times 0{\cdot}35$ square inches. The cables are concentric, lead-covered and iron-armoured, and are laid in wood casing and covered with asphalt; they were made by Messrs. Berthoud Borel & Co. of Cortaillod (Switzerland). Special joint-boxes are used for coupling up. At twelve places upon the circuits, switches are arranged so that any district may be cut off, and fuses are placed there, so that a defective circuit will be automatically cut off; these switches are placed in pillars similar to English pillar-boxes. The transformers reduce the pressure from 2,000 volts to 72 or 36 volts; the latter is stated to be advantageous when arc lamps are used.

The apparatus are of various sizes from 1,250 to 25,000 watts, and details are given as to loss in magnetization, which is 3·3 per cent. with the smallest and 1·2 per cent. with the largest size. The cores are of thin iron plate of E section, and two are put together E ∃ thus, and the windings passed through the openings. Blathy electricity meters are used, and the Author describes them in detail. The arrangement of the station is due to Mr. Coerper.

The Author states that with 102 alternations per second, the flickering in arc-lamps is much less than with fewer alternations, and the glow-lamps prove satisfactory except when the load is changed over from the small to the large machines.

The cost of the station was as follows:—

	£.
1. Buildings, &c.	18,250
2. Boilers (ten)	6,500
3. Engines, dynamos, and instruments	32,250
4. Cables and transformers	31,000
5. Meters	2,000
6. Preliminary work and expenses	2,500
	92,500

As the station is for a total of 20,000 16 candle-power lamps, the cost per lamp was £4 12*s.* 6*d.*

On October 1, 1891, the equivalent of 1,888 16 candle-power lamps were connected; this had risen to 9,700 on March 1, 1892. The Author gives *in extenso* the conditions for supply laid down by the Town Council.

E. R. D.

The Central Electricity Station at Mulhausen.

By — GLASSMANN.

(Bulletin de la Société Industrielle de Mulhouse, 1892, p. 353 *et seq.*
18 Figs. in text and 11 Plates.)

The Author read a Paper before the Industrial Society of Mulhausen, of which the following is an abstract. The station was opened upon the 15th of March, 1888, and at present the lamps, motors, and other apparatus connected to the circuit represent about 800 HP. Although comparatively small, the station is an example of the most recent practice in this department. It comprises two boilers, two steam-engines, two continuous current-dynamos driven direct, a battery of accumulators, the distributing mains, and the controlling apparatus. The boilers are of the de Naeyer tubular type, built by the Société Alsacienne de Constructions Mécaniques, and the principal dimensions are given. There is a chimney 115 feet high, large enough to allow of great additions to the plant.

The engines are of the inverted compound condensing type, and scale drawings are given in the Plates. The high-pressure cylinder is 15 inches in diameter, the low-pressure 21·5 inches in diameter, and the stroke is 15·5 inches. When making 160 revolutions per minute, each engine develops 180 I.HP.

The speed can be regulated, by means of a counter-weighted governor, between 140 and 160 revolutions, according to the required output.

The exhaust-steam passes normally to the condenser, and thence to the street-sewer; but in case of accident, it can be sent direct to the chimney. The condensing-water is obtained from a well. The consumption of steam per HP. hour, including that used in the jackets, is 17·8 lbs. of water evaporated.

The dynamos were built by Messrs. Siemens and Halske, and have a ring-armature revolving outside the stationary multipolar field-magnets.

The armature is keyed direct upon the engine-shaft. The brushes are carried upon a six-armed star borne by a sleeve, and the outside bearing can be drawn away to allow of repairs to the brush-holder mechanism. All the brushes can be regulated together by one hand-wheel and lever, and there is no commutator, the currents being collected at the outside of the armature itself. The field is produced by six poles, excited by a shunt-circuit. The armature consists of an iron ring of rectangular section formed of iron segments insulated from each other and bolted together. The outside of the windings is turned up true, and the brushes rub upon the windings. Owing to the large diameter of the armature, and the number of windings, the potential between adjacent coils is very small, and sparks are avoided. Room is left in the engine-room for additions, and a third set is to be added shortly.

In order to have a reserve of power, secondary batteries are employed; these are placed in three rooms of the same size, and occupying the space between the ground and the first-floor of the building. The two lower rooms each contain one hundred and twenty-eight cells of the Tudor type, of a capacity of 645 ampere hours, their charging current being 161 amperes, and discharging current 193 amperes. The upper room is at present empty. Besides these there are one hundred and twenty-eight other Tudor cells of a capacity of 375 ampere-hours. The maximum charging current being 63 amperes, and maximum discharging current 75 amperes. The three groups can furnish together 145 HP. for three hours and a half, so that the total output of the station is—

	HP.
Two engines at 180 HP. each	360
Accumulators	145
Total	505

The Author then enters into a description of the Tudor cells, and gives curves of charge and discharge.

The system of distribution consists of three classes of mains, the feeders, the distributing cables, and the house-connections. The fall of potential between the station and the feeder points never exceeds 5 volts. The loss of pressure upon the mains and house-connections does not exceed 2 volts. All the cables are of the Siemens concentric type, for the three-wire system. The three sets of wires are insulated with impregnated jute, the whole is then covered with lead, a second covering of jute, then two steel ribbons spirally wound one over the other, and lastly an external covering of prepared jute. Pilot wires are enclosed in the feeders for attachment to the voltmeters which show the pressure at the feeder points.

The section given of one of the feeders shows three conductors, each having an area of 0·186 square inch. The cables are merely laid in the ground at a depth of 27·5 inches below the surface. Several different types of junction-boxes are shown in the Plates; they are of cast-iron, and connection between the various mains is made by clamps and bolts. The boxes are filled up with a heavy oil in order to ensure perfect insulation.

The Author describes the three-wire system of distribution by the aid of diagrams, from which it appears that the dynamos at the station develop 220 volts, and are run in parallel upon the outer mains, the secondary battery being placed across the mains, and the intermediate wire joined to the centre of the battery.

The daily service consists of three periods:—1. Supply by accumulators alone; 2. Supply by the dynamos and charge of accumulators; 3. Supply by both dynamos and accumulators. There are two switch-boards with all the necessary instruments, and the cells are connected in groups of sixty-four to the three main bars on the

switch-board. The Author then enters into a detailed description of the connections upon the switch-boards, which are of the usual type.

The employment of accumulators allows the dynamos to be run at a high load factor and during the evening only; the persons employed are two fitters, one assistant, and one stoker; besides their work at the station, the fitters are employed in making the house-connections.

A diagram of consumption of current is given for December 1891, which shows that between the hours of noon and 4 P.M., and between midnight and midday, the whole of the supply was taken from the batteries, leaving only eight hours during which the machines were running; during this time one dynamo was at work continuously, and the second for only two hours—5 P.M. to 7 P.M. The single machine was loaded the whole eight hours to the extent of 900 amperes, all the surplus not used on the network, going into the batteries. The second machine was working constantly with the load of 900 amperes for two hours, and the curve shows clearly the economy of this method of distribution.

In the case of house-connections, a supply of less than 15 amperes is given by two wires only; but where more is required, the three wires are brought into the premises. Arc-lamps are run either two in series from the outside main to the intermediate or four in series across the outer mains. Motors which take more than 15 amperes, are to be wound for 220 volts. The unit adopted is the ampere-hour, and the price in English units is 10*d.* per Board of Trade unit for lighting, and 4*d.* per unit for motors. So that the price for power is 2·6*d.* per E.HP. hour. The meters used are of the Aron type.

The lamps and apparatus actually connected to the network were on the 15th of July, 1892, 7,765 incandescent-lamps, 84 arc-lamps, four motors of 0·1 HP. with fans, thirteen motors of 1 HP. each, one motor of 8 HP., three cigar-lighters, one galvano-cautery apparatus, and two installations for the charge of portable carriage-batteries.

E. R. D.

The Electric Lighting of the Orleans Terminus in Paris.

(L'Industrie Électrique, 1892, p. 345. 5 Figs.)

The Paris-Orleans Railway Company have recently lighted their terminus in Paris by electricity. Messrs. Schneider & Co., of Creusot, have supplied and installed the boilers, with their iron chimneys, as well as the engines and dynamos. The instruments and fittings have been furnished by Messrs. Lombard, Gerin & Co., of Lyons, and the cables fixed by the Railway Company themselves. The lighting is effected by means of one hundred and twenty arc-lamps of different candle-powers, divided into sixteen

circuits of about seven arcs in series, and one circuit having a variable number which never exceeds twenty. These circuits are fed by dynamos at a constant potential of 350 volts, except one or two which can be supplied by a constant-current machine working up to 1,000 volts. The arrangement of circuits of seven lamps in series, fed from a machine at constant potential, is very rare, as it is much more usual to run lamps in series with constant current. The lighting is, however, stated to be very satisfactory.

All the circuits are brought to a common switchboard, so that each can be controlled from the station. Separate switches are provided, so that any of the circuits of seven arc-lamps can be connected to the two omnibus bars, between which there is a difference of potential of 350 volts; and either two or three of the circuits can be connected in series by special switches to the 1,000-volt machine.

The arc-lamps are of three kinds: the Bardon, Pilsen, and Thomson-Houston. The last are fed from the constant-current machine. Inside the buildings the leads are bare, and carried overhead; while outside they are insulated and put underground. Lighting lasts from ten to sixteen hours. All the dynamos are direct-current machines of the Ganz type, built by Messrs. Schneider & Co., the licensees for France.

They are two-pole over-type machines with soft steel field-magnet cores, round which the base-plate is cast. The armatures are of the drum type, with longitudinal grooves. The installation consists of two dynamos, each developing 140 amperes at a constant potential of 350 volts, and one dynamo giving a constant current of 12 amperes and a maximum electromotive force of 1,000 volts. The two 350-volt machines are shunt-wound, and each is provided with a Blathy regulator, consisting of a float, which counteracts the pull of a solenoid, and so controls the mercury contacts of a set of resistance coils. It is stated that a Richard recording voltmeter gave absolutely constant readings. The constant-current machine is series wound, and is provided with an automatic regulator, of which details are given.

The dynamos are insulated from the floor by sheets of fibre. The two steam-engines drive a countershaft, from which all the machines are driven by belting. This arrangement has been employed in order to be able to change the dynamo in use, and for this purpose clutch-pulleys are used. A particular arrangement of fast and loose pulleys is also employed, with a view to diminish the friction.

The engines are of the horizontal Corliss type, each of 90 HP. at 75 revolutions per minute; and they can be worked either condensing or non-condensing.

The boilers are cylindrical, with internal flue and tubes; and they work at a pressure of 110 lbs. per square inch. The whole installation was designed by the engineers of the Railway Company.

E. R. D.

The Central Electric Lighting Station at Pontresina.

By E. Meylan.

(L'Électricien, 1892, p. 79.)

The motive-power for the lighting of Pontresina has been obtained by erecting hydraulic works near the Bernina falls, $3\frac{3}{4}$ miles from the town, with a total capacity of 450 HP., of which only half is at present in use. The system adopted is that of a continuous current high-pressure supply with transformers at a sub-station. There are three 75-HP. turbines running at 500 revolutions per minute, each being coupled by means of a flexible coupling with a continuous current dynamo giving 34 amperes and 1,500 volts. The machines are carefully insulated from earth, and can be coupled in series, giving then a total of 4,500 volts on the line, which consists of a pair of 200-mil bare copper wires supported on posts and oil-insulators. The total loss in the line is 11 per cent.

At the sub-station the transformers are placed with their primaries in series and their secondaries in parallel, and a battery has recently been added for the day load.

The machines, both at the generating station and at the sub-station, are provided with suitable switches, so that one, two, or three may be worked in series according to the demand for light, and the Author gives a diagram showing the electrical connections and switches.

G. K.

The Life and Efficiency of Glow-Lamps.

By C. Hauptmann.

(L'Électricien, 1892, p. 201.)

The Author points out that seven or eight years ago, the price of glow-lamps was so high that the cost of replacement when worn out was of far greater importance than the cost of the energy consumed to produce a given illumination, and that consequently the life of a glow-lamp was of more importance than its efficiency. Nowadays, when the cost of manufacture of lamps has been reduced to about one quarter what it formerly was, it is necessary to reconsider the questions of the relative importance of life and efficiency. The Author thinks that the life of a lamp is of little importance relatively to its efficiency and mean illuminating power. To show this, he takes as an example a 16-candle-power lamp with a life of from 300 to 350 hours, and consuming an average of 50 watts. During 1,000 hours, this lamp will have to be replaced three times at a cost of 5*s*. The total work expended

in the 1,000 hours is 50 units, valued at 48*s.* in Paris, and 30*s.* in London. Taking, on the other hand, a lamp of long life, which requires from 63 to 65 watts, the cost of current for 1,000 hours comes to 60*s.* in Paris, and 38*s.* 6*d.* in London. Adding in both cases the cost of lamps, the Author finds that there is a difference of 14*s.* 6*d.* and 6*s.* in favour of the short-life lamps, accordingly as the current is charged for at the Paris or London rate.

The Author next proceeds to describe his experiments undertaken to determine the life history of a number of lamps by different makers. Ten lamps of each type were taken, and run in parallel from a storage-battery. Every 50 or 60 hours the lamps were taken off and tested for efficiency and illuminating power in a photometer. The time after which each lamp failed was noted, and thus the average life was ascertained. The Author gives Tables and curves showing the watt per candle, the decrease of illuminating power, and the life of each type of lamp.

In all fifteen different types were tested, and the following Table gives a summary of the results :—

Maker, or Name of Lamp.	Candle-Power.				Watts per Lamp.	Life in Hours.
	Nominal.	At starting.	After 1,000 Hours.	Average.		
La Française.	16	15·02	5·08	8·50	44·80	1,400
,, ...	10	10·47	5·21	8·00	36·00	1,000
Siemens	16	19·80	11·30	14·00	61·00	600
Gabriel	16	18·00	14·98	16·00	63·00	1,800
,, ...	10	13·55	8·56	9·50	41·00	1,500
Swan-Edison (French) . .	16	18·00	13·00	15·00	67·00	1,500
,, (English). .	16	18·40	13·90	16·00	60·00	1,200
Khotinski.	16	16·50	13·00	14·00	63·25	1,300
Cruts	16	16·40	11·00	13·00	60·00	1,100
Allg. Elektr. Ges. . . .	16	15·00	8·80	12·00	50·00	1,000
,, ,, . . .	10	10·00	5·08	8·50	34·70	1,200
Société Hongroise . . .	16	21·00	13·25	16·00	62·00	1,250
,, de Zürich . . .	16	17·62	7·35	12·00	45·00	600
,, ,, . . .	10	12·92	9·70	10·00	33·00	300
Gérard	10	13·80	11·00	13·00	34·00	500

Commenting on this Table, the Author suggests that the Gérard lamp of 10 nominal candle-power could be used with an average illuminating power of thirteen candles, and an expenditure of 34 watts, which represents a saving of power amounting to nearly 50 per cent. as compared with the older types of 16 candle-power lamps giving the same mean candle-power.

G. K.

The Use of Glow-Lamps as Resistance in Arc-Lamp Circuits.

By C. Heim.

(Elektrotechnische Zeitschrift, 1892, p. 375.)

The Author states that all central stations in Germany supply current at between 105 and 110 volts pressure, and arc-lamps must be run two in series for economy. In many cases, however, a single lamp of 4 to 6 amperes is quite sufficient. The consumer has, therefore, only the choice of using either two of the smaller lamps, or one lamp with a resistance in circuit to lower the potential by 60 to 70 volts. The first method means high first cost, and the second high cost for maintenance, as only about 40 per cent. of the energy is used. It is not, however, possible always to arrange for an even number of arc-lamps, even in large installations, and arcs in series never burn so well as one on a circuit of 65 volts, as the irregular action of one lamp affects the other. The variations in potential difference between the terminals of each lamp cannot be made less than 5 per cent., and it is almost impossible to avoid great fluctuation in the first quarter of an hour after lighting. It is also well known that an arc burns better the higher the electromotive force used, and the greater the energy wasted in artificial resistance. If a shunt-wound lamp be worked on 100-volt circuit with a large resistance in series, there is no perceptible flicker, and the potential difference does not vary 2 per cent.

The numerous lamps of this class experimented on by the Author led him to consider that a number of glow-lamps in parallel might be used as the artificial resistance, at the same time employing their light. It only remained to decide whether the variations in potential would prejudicially affect the glow-lamps. The fluctuations depend upon the relation $\frac{E}{i}$, where E is the potential between the terminals of the lamp at any instant, and i the corresponding current. The Author then gives his reasons for considering that an arc-lamp would burn more constantly with glow-lamps in series than with a second arc-lamp.

In order to test this point, a group of 16 candle-power 63-volt lamps were placed in series with a shunt-wound lamp, and the number of lamps could be varied. One lamp was placed in a photometer at a distance of 9·8 feet from a petroleum-lamp of constant power, and the whole of the lamps were fed from a battery in order to be sure that any variations observed were caused by the arc-lamp. For the sake of comparison, tests were also made with current from a dynamo. This machine was driven by a twin gas-engine which was not allowed to miss explosions, and the results agreed with those obtained with the battery.

The potential difference was measured with a torsion galvanometer, and also the current. In the photometer tests it was not

essential to know the absolute candle-power of the lamps, but merely the percentage of fluctuation. Observations were also made as to the number of times the carbons were fed in a given length of time, and no tests were made until the whole of the lamps had been lighted half-an-hour.

In this manner three arc-lamps of different construction and size were tested: lamp I took 4 amperes, lamp II 6 amperes, and lamp III 9 amperes.

In lamps I and II, the controlling magnet was in series with the carbons, and in III it was in shunt. In the Table the observations for each lamp are given with the maximum variations; these, however, did not occur at the time the carbons fed.

No. of Lamp.	No. of Feeds per Minute.	No. of Glow-Lamps used.	Total Potential Difference.	Potential Difference in Volts.		Average Current in Amperes.	Percentage Variation in Candle-Power of Glow-Lamps.	Percentage Variation in Potential Difference.	
				Glow-Lamp.	Arc-Lamp.			Glow-Lamps.	Arc-Lamps.
I	11	5	103	59·5–59·0	40·4–41·0	4·3	5·5	0·85	1·5
II	8	8	110	62·0–61·3	44·2–44·9	6·4	6·9	1·1	1·6
III	4–5	12	108	62·1–61·3	44·2–45·0	9·4	8·0	1·3	1·8

From an examination of the lamps themselves, practically no change in light was perceptible. This was especially the case with lamp I; with lamp III a slight flicker could be noticed on close observation.

By causing the carbons to feed at short intervals of time, the fluctuations are diminished. In the case of lamp II, when the feed took place eight times per minute instead of four times, the fluctuation in the glow-lamps diminished from 9·5 per cent. to 7·5 per cent., while the fluctuation in potential difference between the lamp terminals was reduced from 2·9 per cent. to 1·8 per cent. at each feed. The average potential difference required for the 4-ampere lamp was 42 volts. It might appear from the Table that the fluctuation in light varies directly with the quantity of current used; but this is not the case, and the more frequently the feed takes place the less fluctuation will there be. It is best to have a small resistance which may be put in circuit until the arc-lamp is running properly. For the three lamps, the following resistance is advisable: Lamp I 1 ohm, lamp II 1·7 ohm, lamp III 0·4 ohm.

It appears that the system described has been in use for some time at the Central Hotel in Berlin.

E. R. D.

The Age-Coating in Glow-Lamps.

By Edward L. Nichols.

(American Journal of Science, 1892, p. 277.)

This Paper, containing results of experiments by Messrs. Moore & Ling, of the Physical Laboratory in the Cornell University, determines that part of the diminution of efficiency in glow-lamps which is due to the obscuration of the bulb by deposited carbon. The distribution of this deposit is very nearly uniform over the whole surface, and the colour is of neutral tint, so that all the rays of the spectrum are equally affected. The rate of deposit is greatest in the early part of the life of the lamp; and in lamps of high initial efficiency the absorption of light by the age-coating forms a larger part of the total loss than in those of lower efficiency; while no marked difference could be appreciated between filaments which had been treated or not.

The following Table contains the quantities which were determined in the case of one lamp under trial, where the initial values are taken as one hundred.

Time. Hours.	Relative Brightness.	Relative Efficiency.	Relative Transparency of Bulb.
0	100	100	100
100	78·1	81·5	91·4
200	67·5	70·9	85·9
400	60·4	66·8	82·5
800	45·0	51·3	78·2

A note is added that since this article was written it has been pointed out by Professor B. F. Thomas that in lamps exhausted without the aid of mercury the age-coating is scarcely perceptible.

F. J.

Electric Railway on Mount Salvator. By E. Meylan.

(L'Électricien, 1892, p. 53.)

This is a cable railway serving the tourist traffic to the "Pic de San Salvatore," near Lugano. The line is of metre gauge and 1 mile long, rising in that distance 2,000 feet. The hauling machinery is placed midway, and consists of a cable-drum with a countershaft which may be driven either from an electric motor or

from a portable engine. Two carriages are simultaneously in motion, one running from the lower terminus to the engine-house, and the other from the engine-house to the summit. The passengers change carriages at the engine-house. The carriages weigh 4½ tons and seat forty-eight passengers, and the journey is performed in half an hour, giving a mean speed of nearly 3 feet per second. The cable to which the lower carriage is attached goes over a winding-drum and an idle pulley, and is then carried up to the top of the line on guide-pulleys, where it passes over a sheave and down to the second carriage.

The cable is 1¼ inch diameter and weighs 7 lbs. per yard.

The electric-motor is a 50-HP. nominal continuous current machine running at 700 revolutions per minute, the current being supplied at 1,800 volts, from a generating station 4½ miles distant, by two 200-mil copper wires carried overhead on wooden poles and oil-insulators. The same posts carry also two 240-mil wires through which alternating currents for lighting the town of Lugano is supplied. At the generating station the power is obtained from the turbines, one of 125 HP. for working the continuous current transmission plant, and the other of 250 HP. for working two alternators. The combined powers and lighting plant has been erected by the Oerlikon Engineering works.

G. K.

The Bremen Electric Tramway. By E. Meylan.

(L'Électricien, 1892, p. 121.)

Two of the tramway lines in Bremen are worked electrically. The length of road is 4 miles, of which 1½ mile is double. The maximum gradient is 3 per cent., and the curves are easy. The current is supplied, at 500 volts, by trolly wire, suspended either from posts or from cross wires attached to the house fronts. The speed is limited to 7½ and 10 miles per hour within and without the town respectively. There are now ten electric cars, five being simultaneously in use on week days and seven on Sundays. Each car is fitted with a 15-HP. motor, and is powerful enough to draw an ordinary car coupled to it. The generating station occupies an area of 4,750 square feet, and the chimney is 120 feet high, and from 5 feet to 6 feet 3 inches internal diameter. Two Babcock-Wilcox boilers, each of 1,400 square feet heating-surface, supply steam at 115 lbs. to two McIntosh and Seymour compound condensing engines, indicating 141 I.HP. at 230 revolutions per minute. The fly-wheels are specially heavy, and, in conjunction with the governors, keep the variation of speed to within 1 per cent. The coal consumption is 2·7 lbs. per HP. hour. To these engines are belted two Thomson-Houston 4-pole Gramme-wound dynamos of 80 kilowatts capacity, running at 700 revolutions per

minute. These machines have ball-bearings lined with magnolia metal. The lines were opened on the 1st of May, and the number of passengers carried up to the 8th of June was 98,676, being 30 per cent. in excess of the number carried during the corresponding period in the previous year when horse-traction was employed.

G. K.

On Electric Locomotives in Mines. By C. Baily.

(Revue Universelle des Mines, vol. xix., 1892, p. 107.)

At the No. IV pit of the Mines de Marles, near Bethune, Pas de Calais, traction by electric locomotives has been applied experimentally in two galleries, driven in opposite directions, the northern one being new, and representing more favourable conditions in regard to inclination and humidity than the southern, which is considerably older. These have been chosen in order to arrive at the conditions under which the system can be most advantageously applied. The installation supplied by the Edison Company is designed to work two locomotives capable of developing 10 HP. with a current of 30 amperes and 400 volts, and utilizing 70 per cent. of that given out by the dynamo. The engine with cylinder of 400 millimetres (15¾ inches) diameter, and 800 millimetres stroke, making 65 revolutions per minute, drives the dynamo by means of a belt at 840 revolutions. The main conductors on the shaft are insulated cables of copper, 9 millimetres (0·35 inch) diameter, supported on porcelain belts at intervals of 30 metres, which are connected with a switchboard at the pit-bottom for turning the current either to the north or south gallery as required. The conductors in the gallery are flange rails weighing 6½ kilograms per metre (13 lbs. per yard), which are hung from the roof and insulated by disks of india-rubber.

The locomotive is a 15,000-watts series dynamo, mounted on an iron carriage with two axles, which are driven by an intermediate shaft and toothed gearing, the axis of the dynamo being parallel to the road. The current is taken from the conductors by two small carriages drawn by the locomotive. The electromotive force, and consequently the power of the engine, may be varied by a rheostat placed in the circuit, which acts upon the magnetic field of the main dynamo, so that it is very easily controlled. There is also a quick-acting disconnecting gear at either end for admitting or cutting off the current for the locomotive, as well as a reversing gear by changing its direction. The dimensions are: length, 2·30 metres (7·54 feet); breadth, 0·72 metre; and height, 1·50 metre. The weight, which was originally 1,800 kilograms, being insufficient for the south gallery, where the adhesion is deficient, it has been increased by the substitution of solid wheels and counterpoises to 2,300 kilograms, which is found to give perfect adhesion and stability. The loss of current on the line is imperceptible.

In order to determine the mechanical efficiency of the arrangement, a series of experiments have been made on the southern gallery on a length of 400 metres, with a rise of 1 degree, with the engine alone, and with trains of variable lengths, running at different speeds, with the regulator open or shut. The figures obtained are given in detail and an abstract of the results in the following Table :—

Experiment.	Moderator.	Tubs in Train.	Speed per Second.	HP. of Surface Dynamo.	Effect in HP., including Locomotive.	Useful Mechanical Effect.	Useful Industrial Effect.	Weight.
No.						Per cent.		Kilograms.
1	Shut	..	2·50	10·86	3·06	27·00	..	2,370 (engine only)
2	Open	15	2·38	19·33	11·30	58·50	43·38	3,660 (train without engine)
3	Open	12	3·46	18·21	14·00	77·00	54·48	2,950
4	¾ Open	12	2·50	17·37	10·00	57·50	40·70	2,950
5	Shut	4	1·49	13·96	3·37	24·07	12·46	1,217
6	¾ Open	8	3·20	16·14	10·00	61·95	38·56	2,004

By useful industrial effect is meant the work of moving the train, apart from the engine. The effect of the moderator is only to limit the quantity of current, but not to regulate it. When closed, as on the first and fifth experiments, the current varies from 16 to 20 amperes; and when full open, the quantity is the same, the difference of work being due to the voltage. In the fourth and sixth, with three-quarter open, there is a reduction from 30 to 25 amperes. This is due to the self-regulating character of the locomotive, which varies the expenditure of power with the work to be done. It is therefore a point of importance to keep the gradient of the line as uniform as possible, in order that the current may never exceed the maximum that can be safely borne by the rheostat. A comparison of the second, third, fourth, and sixth experiments shows that it is better to increase the speed rather than the load. Electric machines work best at high speeds. In the third and fourth experiments the speed is seen to be increased 40 per cent. with the same load, while the extra power expended is only 5 per cent., the maximum useful effect being obtained at a speed of 3·46 metres. This, however, is likely to be too high, except on straight roads of greater length, free from crossings and the conditions of the second experiment. The engine drawing fifteen tubs at 2·50 metres' (9 kilometres per hour)

speed will probably be more suitable. At this rate the engine could furnish in coal drawn, 243 ton-kilometres in the shift of eight hours. With horse-traction, having regard to the bad state of the road, five horses (four at work and one relief) will be required to do the same amount of work. The two locomotives, therefore, when in full work, the only conditions under which they can be profitably employed, will replace ten horses. The working cost being £1 12*s.* 10*d.* in the first case, and £2 17*s.* 6*d.* in the second, there is a difference of 42·5 per cent. in favour of the electric method of transport.

A further considerable advantage is likely to be obtained by the use of the line for travelling by the miners. When the working faces are 2 kilometres from the pit-bottom, half an hour will be saved by carrying the men to and from their work, allowing an increase of working time of $\frac{1}{16}$, or 6 per cent., or fifty full shifts on the eight hundred men employed underground.

The cost of the installation has been:—

	£	*s.*	*d.*
Steam-engine	422	10	0
Steam-pipes and other accessories of erection, &c.	243	15	4
Dynamo at the surface	197	7	6
Insulated conductors, 630 metres	72	14	0
Erection of electrical arrangements and sundry charges	132	5	0
Total of fixed plant	1,068	11	10
1,400 metres of electric line, materials and laying	319	4	0
Three locomotives	780	0	0
Total	2,167	15	10

H. B.

The Electric Mine-Railway at Bleiberg, in Carinthia.

By E. Markuc.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, 1892, p. 72.)

At the lead-mines of the Bleiberg Union, which cover a considerable extent of ground, the mineral from the different working places is brought to a main drawing-shaft, the Rudolph shaft, 121 metres deep, connected at the surface with the central dressing floor, along the adit-level in tubs containing 560 kilograms, which, when pushed by hand for a distance of 900 metres, employed a force of twenty-one putters, making nineteen journeys in the shift, in order to supply the daily output of 224 tons. The working of the dressing floor being in some danger of interruption from the disinclination of the putters to work regularly during the season of active operations, which is confined to the nine months, April to December inclusive, or two hundred and thirty-four days, it was determined to substitute mechanical for hand-

traction in the adit, and, as there was 8 HP. available at the dressing floor, it was determined to utilize it, partly for lighting and partly for hauling purposes. For the former purpose thirty incandescent and two arc lights have been provided, saving about £100 per annum upon the former cost for illumination; while for the second an electric railway has been established in the adit, the whole being constructed by Messrs. Ganz and Co., of Buda-Pest.

The railway is different in many respects from those previously established in collieries and other mines with large and regular levels. Both shaft and adit are very wet, rendering special care necessary in the insulation, and the latter is crooked and so narrow that the dimensions of the locomotive are restricted in breadth to 700 millimetres, with a gauge of 430 millimetres, and a height of 1,700 millimetres from the top of the rails to the overhead conductors. The work, which is limited by the capacity of the winding-engine of the shaft, consists in drawing forty trains of five loaded tubs in the shift of ten hours, with a mean speed of 3 metres per second (11 kilometres per hour). The tub weighs 200 kilograms, the load 560 kilograms, and the engine 1,550 kilograms, giving a total weight per train of 5,350 kilograms, which, on a level line with a traction coefficient of 1 per cent., requires a mechanical effort of 161 metre-kilograms, or 2·15 HP., the corresponding electrical energy being 2·15 by 736, or 1,600 watts, or, allowing for resistance in the conductors and eight glow-lamps on the road, about 2,500 watts as the normal working current, which, however, is considerably exceeded at starting. The dynamo, of compound construction, is designed for a maximum of 6,000 watts at 700 revolutions per minute, giving a current of 220 amperes and 22 volts. The engine-house is 95 metres from the shaft; the current is conveyed to the latter by two 6-millimetre copper wires, and thence down to the adit by a cable with two triply insulated wires covered with lead, which is laid in a waterproofed wooden case in the footway division of the shaft, so that it may be readily accessible. The line conductors are 6-millimetre wire, of silicon bronze, which are supported by insulators 330 millimetres apart and 1,700 millimetres above the rails. These insulators are roofed with sheet-zinc and connected by pieces of galvanized wire-rope to other bracket insulators fixed to the sides of the level. This arrangement gives a double insulation which is of some importance, as the rock, from its numerous lodes and cross courses, has a not inconsiderable conductivity. In order to divert the current at points of junction the insulated line carriers are mounted on a sliding frame, so that they can be shifted laterally from one to the other line. These points are marked by incandescent lights.

The locomotive, which is about 2·5 metres total length, has two axles, 1 metre apart, carries a motor with a Hefner-Alteneck armature and 46-part commutator, making the same number of revolutions, 700, as the primary dynamo, which is reduced by a

screw and worm-wheel to 88 revolutions on the driving-shaft, and to 34 revolutions on the front driving-axle, by chain gearing, in order to obtain the required speed of 3 metres per second. The driving-axle is coupled to the hinder one by a similar chain, the total adhesion weight of the engine being required for the full train of five vehicles. When only the front axle is driving, the load must be reduced to three.

The current is taken and returned by a pair of curved tubular arms, forming spring poles, with insulated iron plates at their ends upon spring carriers, which maintain a sliding contact with the line wires. The latter have been made of silicon bronze, in preference to copper, in order to resist abrasion by the rubbing of the contact-plates.

The results of the trials show the insulation to be very perfect, the loss of tension being less than was expected. The total current used, as measured at the generating dynamo, varied between 8 and 16 amperes, the meter rising to 35 amperes at the moment of starting, while in smooth running it oscillates between 8 and 12 amperes. The average energy required for working the line and the lighting of the road and the engine, including all losses in the conductor and magnetic friction, is $220 \times 10 = 2{,}200$ volt amperes, or 3 HP., and, as the motor does 2·15 HP. work, the efficiency is 70 per cent.

The installation, costing £1,300, does the work of twenty-one putters in the level, their place being now taken by sixteen fillers, at lower wages, the total saving being given at from £352 to £400 per annum. The lighting up of the crossing points of the branch-levels and the shaft-bottom, which is done by pairs of 16-candle glow-lamps, is also found to be of great advantage to the miners.

H. B.

Safety-Attachment for Electric Mains. By K. Wilkens.

(Elektrotechnische Zeitschrift, 1892, p. 368. 1 Fig.)

The superiority of an automatic cut-out over the ordinary fusible cut-outs is evident; but its higher price and somewhat complicated details have prohibited it from extended use. As regards the cost of production, it cannot be compared with the price of an apparatus with fusible cut-outs, without taking account of the cost of renewal of the fuses. The readjustment of the circuit is more difficult with fusible cut-outs than with the automatic apparatus, and if the cut-outs are not at hand, may lead to danger. In order to lessen chances of annoyance it is best to have duplicate fuses, which can be switched in when the first have melted. An advantage of the automatic cut-out is that it is always set for the same current. With lead-plug fuses each size

must be made so that it will fit no smaller cut-out; and though this can be done, it complicates the installation. The main points to be observed in the construction of an automatic cut-out are that the apparatus must not be subjected to change; the consumer must be able to replace the apparatus after it has acted, and it must not be possible to render it inactive by tying up the handle. With these data in view, Messrs. Hartmann and Braun, of Bockenheim, have designed an automatic double cut-out, of which the essential parts are a current-measurer, a cut-out gear, and two cut-outs. In order that the apparatus may serve for either alternating or direct currents, the current-measurer is in the form of a solenoid with soft iron core.

The counter-balance is a spring regulated by a screw. The core is supported at one end of a lever, while the other is provided with a small roller, against which the cut-out gear is pressed by a spring. The cut-out gear consists of a flat spring fixed at the upper end, and provided with a projection which serves as fulcrum for the cut-out lever. The spring of the current-measurer is of such a strength that on the passage of the normal current the small roller on the lever comes before the turned-up part of the flat spring. If the current rise above its normal the roller comes against the turned-up part, the flat spring is then released, and the cut-out is freed, and snaps out of its contacts, and the circuit is broken. A special lever is used to reset the apparatus. In places where the energy is supplied for a stated time, and where the consumer must be prevented from using more than the normal current, this instrument serves perfectly. In order to show the satisfactory working of the apparatus, the Author gives two Tables extracted from a report of the electric testing-station at Munich. One Table shows the value of the current which caused a cut-out when the instrument was cold, and the other shows the value at cut-out after a current near the maximum had flowed through the instrument for two hours. The current was produced by a machine giving one hundred alternations per second. The Tables show that when cold the instrument cut out with a current of 7·37 amperes, and when warm with 7·21, each of these values being the mean of a series of nine tests. The variation in the current required to cause the cut-out never exceeded 0·06 ampere. A failure to act was never observed.

E. R. D.

Apparatus for Testing Transformer-Iron. By — SCHWOLLER.

(Elektrotechnische Zeitschrift, 1892, p. 353.)

This was a Paper read before the Electrical Society of Berlin, and in it the Author described an apparatus devised for measuring the hysteresis and Foucault losses in samples of iron plate of the kind used in the manufacture of transformers. Instruments for the determination of the permeability have been constructed by Edison, Eickmeyer, Siemens and Halske, and others, but these are not applicable, since they do not give the energy wasted in rapid magnetic reversals. In the method described by the Author the sample is cut up into rectangular strips, from which a prismatic core is built up, paper being used for insulators in the well-known manner. The core is placed between two electro-magnets with laminated cores, each of half the sectional area of the sample so as to obtain the same induction throughout the magnetic circuit. The induction is determined from the number of turns of the electro-magnets, and the terminal voltage, and the power expended with any current of known frequency is measured on a wattmeter. The sample is then withdrawn, and the electro-magnets are joined direct at their poles of opposite polarity, and the power is again measured. The difference between the two power-measurements gives the loss due to hysteresis and eddy currents in the sample. The Author states that the values thus obtained with ordinary commercial iron exceed Ewings' values from 60 to 70 per cent.

G. K.

On the Thermal Variation of the Electrical Resistance of Mercury. By C. E. GUILLAUME.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxv., 1892, p. 414.)

The glass tubes containing the mercury were taken of such size (30 grams per ohm) so as to allow of the use of currents of sufficient intensity for accurate measurements; and two methods of balancing on the Wheatstone Bridge were adopted; one by using a calibrated wire for measuring the difference between the resistances of the heated and standard tubes, and another by shunting the higher resistance until equality was again established. The terminal contacts were of three forms, each described in detail; and results are given for the apparent alteration in hard glass, and also when reduced to the normal scale.

The numerical results obtained by both the methods are thoroughly concordant, and, if introduced into the measurements of the ohm, make the value somewhat higher than those given by the majority of previous observers; but the mean of the best observations makes the ohm practically 106·3 centimetres of mercury of one square millimetre section at 0° Centigrade.

F. J.

On Electrical Discharges through Poor Vacuums.

By M. J. Pupin, Ph.D.

(The American Journal of Science, 1892, p. 463.)

In investigating the phenomena of electrical discharges in rarefied air, it is customary to employ a vacuum jar with metal electrodes, in connection with a generator of small capacity. The Author produces an alternating discharge in vacuo without any electrodes at all, and claims that the method of doing so was worked out by him several months before the publication of Nikola Tesla, and Professor J. J. Thomson's experiments.

The poles of a small Ritchie induction coil were connected with two beakers containing water. The primary was fed by a $\frac{1}{4}$-HP. alternator giving about 80 periods per second. A resistance-box placed in the circuit served to regulate the current. The vacuum-tube was shaped like a cryophorus, *i.e.*, it consisted of two glass bulbs about 8 centimetres ($3\frac{1}{4}$ inches) in diameter connected by a tube of narrow bore, bent down at the ends, so that the bulbs could be immersed in the beakers to any desired depth. The pressure of air in the apparatus was about 5 millimetres ($\frac{1}{5}$-inch). As soon as the bulbs reached a certain depth in the liquid a steady crimson luminosity appeared, the intensity of which increased as the surface of contact grew larger. The Author investigated the effect of varying the pressure of the gas, and the frequency and electromotive force of the alternations. He found that there was a critical difference of potential below which the discharge would not continue, and to start it again this value had to be exceeded. The electrical glow seemed to be confined to a thin layer of the rarefied air in contact with the glass. A gliding film of luminous gas extended from the mouths of the connecting tube, and spread over the inside surfaces ending at the bottom of the bulbs in a tumultuous cloud.

In another set of experiments a spherical electrode was fixed in the centre of an exhausted bulb, the outside of which was coated with tin foil, so as to form a condenser. The Author suggests the name of "coronoidal discharges" for the phenomena observed with this arrangement, some of which he has photographed to illustrate the Paper.

G. J. B.

On the Employment of Manganin for Resistance-Coils.

By — MILTHALER.

(Annalen der Physik und Chemie, 1892, p. 297.)

On account of its high specific resistance, and small negative temperature-coefficient, manganin,[1] composed of copper 83 per cent., nickel 4 per cent., and manganese 13 per cent., may be advantageously employed in the manufacture of resistance-coils. The Author found that after such a coil had been heated to about 100° Centigrade, its resistance was diminished by from 0·4 to 0·8 per cent.; but on repeating the process the alteration became less and less, until it amounted to no more than $\frac{1}{20,000}$ of the whole.

He recommends, therefore, that the coils should be heated to 110°, and kept at that temperature for some hours every day for a month, in order to get rid of the molecular disturbances due to the processes of manufacture; and that they should be well paraffined to preserve the alloy from air and moisture.

G. J. B.

A New Method of Producing Gutta-Percha for Insulating-Purposes. By — JUNGFLEISCH.

(L'Industrie Électrique, 1892, p. 302.)

The increasing scarcity of gutta-percha, and the rise in its price has caused much attention to be given to its methods of production. Mr. Serullas and Mr. Seligmann-Lui have been to the East Indies on special missions for the purpose of studying the methods in use for collecting the gutta-percha. Although the botanical characters of the trees which produce gutta-percha were well-known, it was not understood which particular variety of tree gave the best quality of gutta-percha for insulation purposes. Mr. Serullas found, in 1888, that the Isonandra Gutta gave the finest quality. The Malays could only obtain the raw product by their method from trees of twenty-eight to thirty years' growth, or from re-growths fourteen to fifteen years old. The Author states that their custom was to cut the trees down, and that then they only obtained about 0·58 lb. of raw gutta-percha from each tree as a maximum, and this was largely charged with impurities. Mr. Serullas obtained by a more careful treatment only 0·48 lb. from a tree of thirty years' growth, and he saw a tree of 47 inches dia-

[1] Feussner, Electrotechnische Zeitschrift, 1892, vol. xiii., p. 99. See also Feussner und Lindeck, Zeitschrift für Instrumentenkunde, 1889, vol. ix., p. 233, and L'Électricien, 1892, p. 357.

meter cut down which only gave 0·84 lb. of the raw product. As the exports in 1884 reached 3,145 tons, this meant a destruction of twelve million Isonandra-trees of thirty years' growth in that year alone, so that it was probable the supply of gutta-percha would soon cease altogether. The Author arranged with Mr. Serullas that the latter should send home from the East Indies the leaves and shoots of the trees in order that experiments might be made to see if the gutta could not be obtained from these parts without the necessity for cutting the trees down. It was found that there were many solvents by which the gutta could be extracted, and at present the best results have been obtained with toluene; it dissolves the three compounds of which gutta-percha consists, and does not dissolve the other vegetable matters except chlorophyll. The process has been tried upon leaves sent to France dry, upon fresh leaves sent over in antiseptic solution, and dried on arrival; shoots dried and stripped of leaves, and upon wood of two years' growth, dry and stripped of leaves. All these parts gave approximately the same favourable result. The method of extraction is simple. The material is torn up small and digested at 212° Fahrenheit, then treated with toluene. A solution of gutta-percha coloured green by the chlorophyll is thus obtained; the toluene is then carried off by a current of steam at 212° Fahrenheit as a maximum temperature. The results obtained gave 9·0 to 10·5 per cent. of gutta-percha from the material treated. It appears that the gutta-percha itself is colourless, and that the usual brown tint is due to other vegetable constituents. The Author states that if the leaves are sent direct to Europe, it will be possible to obtain the best qualities of gutta-percha without adulteration, and that a tree of thirty years' growth would give each year easily 24·2 lbs. of dried leaves, and, therefore, 2·2 lbs. to 2·4 lbs. of gutta-percha, instead of 0·58 lb. as before by destruction of the tree. The Author believes that in this way the electrical industry will be able to obtain at a low rate all that it requires.

E. R. D.

Investigations on the Favourable or Injurious Influence of the Usual Admixtures to India-Rubber and Gutta-Percha upon the Technical Use of these Substances.

By Dr. C. Heinzerling and W. Pahl.

(Verhandlungen des Vereins zur Beförderung des Gewerbefleisses, 1891, p. 351.)

After sketching the history of india-rubber and gutta-percha, the Authors give statistics of the trade in these articles, and then describe the process of manufacture. The raw india-rubber is first torn into pieces and washed by means of rollers, the loss in weight being from 12 to 30 per cent. The washed material is then carefully dried and ground between rollers revolving twenty

times a minute. In order to modify the colour of the india-rubber it is mixed with talc, zinc oxide, white lead, litharge, cinnabar, antimony sulphide, lampblack, &c., while barytes and chalk serve to increase the weight.

The vulcanizing of india-rubber is effected by heating the substance with sulphur, or a sulphide such as lead or antimony sulphide; the latter for red goods. For ebonite the proportion of sulphur used is 20 to 35 per cent., while 10 per cent. is the proportion mixed with india-rubber which is to retain its elasticity. In the latter case, the mixture is heated to 280°–309° Fahrenheit (120°–136° Centigrade), and in the former to 316°–319·6° Fahrenheit (140°–141° Centigrade). During this process only part of the sulphur is chemically combined; the remainder is in a state of mechanical admixture, and sometimes effloresces on the surface of the goods. The substances mixed with ebonite, according to the uses for which it is intended, are gutta-percha, gum balata, resin, asphalt, magnesia, lime, &c.

The treatment of gutta-percha differs somewhat from that of india-rubber. The raw material is first cut into pieces by a cutting-machine, and then immersed in water, in which most of the impurities sink, while the pure gutta-percha floats. The mass is then warmed and kneaded in a special machine, and substances similar to those used with ebonite may be added at this stage. In judging the quality of india-rubber and gutta-percha, the specific gravity and percentage of ash have hitherto been taken as guides; but the Authors find that for some purposes the quality is much improved by the admixture of certain mineral substances, and the specific gravity may be modified by adding substances such as paraffin-wax or thickened oil, which may be even lighter than the pure material.

In procuring the samples with which their experiments were made, the Authors either had them specially prepared according to their instructions, or the composition was communicated to them by the manufacturers.

Samples of different composition were subjected to the action of various chemical substances, viz., sulphuric acid, acetic acid, soda solution, ammonia, refined colza-oil, mineral lubricating oil with the addition of tallow, illuminating gas. The test-pieces were carefully measured before and after exposure to the action of the different reagents, it having been found that the india-rubber swelled as soon as any injurious action commenced. Among the physical tests carried out were the determination of the limit of elasticity, the deformation under high pressure, deformation under percussion, and the determination of the insulating capacity.

The results of the different tests are given in numerous Tables. Some of the commercial samples were stored for two and a half years, and it was found that certain substances, such as zinc oxide and chalk, although they increased the strength and insulating power of the fresh material, caused considerable deterioration after long storage. Soft rubber containing basic admixtures such

as magnesia, zinc oxide, lead oxide, or chalk, was more easily acted upon by acids than pure rubber; but in some cases these admixtures increased the resistance to the action of mineral and vegetable oils. Alkalies and illuminating-gas had so little action upon all kinds of india-rubber that differences of practical importance could not be observed. Most of the organic admixtures, especially paraffin, resin, and pitch, preserved the insulating capacity in a high degree; but india-rubber containing them did not resist the action of high temperatures well.

The quality of hard rubber or ebonite was much deteriorated by the addition of resin-oil and resin; but asphalt increased both strength and elasticity. Hard rubber resists chemical action much better than the soft material. Among the general conclusions drawn by the Authors from the results of their experiments, the following may be mentioned.

All mineral and organic admixtures diminish the elasticity of soft rubber goods; 10 per cent. of sulphur was found to be the best proportion for vulcanization. The elasticity of hard rubber may be increased by certain organic and mineral substances. The strength of both soft and hard india-rubber may be increased by the addition of some organic or inorganic substances, but is materially diminished by others. Numerous compounds were found to possess better insulating qualities than pure india-rubber mixed with sulphur alone. All organic admixtures produced vapours when heated to a high temperature. Most varieties of india-rubber containing mineral matter become hard and brittle if stored for several years; but the insulating-power appears to remain constant.

A series of samples of gutta-percha with different admixtures was tested in the same way as the india-rubber, but special attention was directed to the insulating-capacity. The resistance to chemical reagents was not appreciably influenced by the substances added. Pure gutta-percha and gum-balata were found to be the best insulators. Insulation was diminished by the addition of cinnabar, hydrate of lime, resin-oil and resin, while it was not affected by asphalt added in quantities not exceeding 30 per cent. The limit of elasticity was slightly increased by cinnabar and hydrate of lime, while the strength was increased by the former and diminished by the latter substance.

The Paper is accompanied by Tables and curves giving the results of the mechanical tests.

W. F. R.

Bolometric Researches.

By Dr. O. Lummer and Dr. F. Kurlbaum.

(Annalen der Physik und Chemie, 1892, p. 204.)

This Paper describes the construction of a bolometer of great sensitiveness and rapid action, which may be used in photometric investigations. A piece of platinum foil is welded to a sheet of silver about ten times its thickness, and the compound plate rolled out as thin as possible. After this it is placed in a folded sheet of copper, and still farther reduced. When sufficiently thin it is cemented to a piece of glass, and parallel strips cut out alternately from opposite sides so as to make the path of the electric current as long as possible. It is then separated from the glass, and cemented on to a square frame across which the bars of platinum-silver form a sort of grating. Finally the silver is dissolved by means of nitric acid from off the central portions, the ends being protected by a varnish so that they may serve to support the bars, and afford a means of connecting the bolometer with the circuit. Full details of the method of manipulation are given in the Paper.

G. J. B.

Experiments on Air-Resistance.

By — Cailletet and — Colardeau.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxv., 1892, p. 13.)

A body dropped from a great height does not fall with uniformly increasing speed, but assumes after a certain time a sensibly constant speed at which the resistance offered by the air balances the weight. By observing the fall of bodies it is thus easy to determine the air-resistance at different velocities. Such observations were made by the Authors on the Eiffel Tower by means of a specially devised apparatus placed on the second platform, which is 390 feet from the ground. This apparatus consists of a wooden box containing a central opening through which the body is let fall, and round which opening is a corner of cone-shaped bobbins, on each of which is wound a length of 20 metres (65 feet 6 inches) of thin line, the ends of the lines being connected and passed through contact forks. The moment the line has been completely unwound from the first bobbin it slips through the corresponding contact fork and begins to unwind from the second bobbin and so on. An electric current actuating a magnet in connection with a chronographic recorder is sent through all the contact forks in series, and the momentary interruption of the current due to the line slipping through any of the forks is thus registered by the chronograph. The free end of the line is attached to the falling body, and thus the time intervals at which it has completed suc-

cessive distances of 20 metres in its descent are recorded. The Authors state that by comparative experiments between bodies falling free and the same bodies falling with the line attached, it was found that the error due to the resistance of the line was only 0·04 of a second over a total of 5 seconds.

With this apparatus it was found that for plane surfaces placed at right angles to the direction of the wind, the wind-pressure depends only on the total area and the velocity, but not on the shape of the surface. The resistance for the same velocity was found to be directly proportional to the area, but the generally accepted law, according to which the resistance is supposed to be proportional to the square of the velocity, was not confirmed, the Authors having found that the resistance increases a little faster than the square of the velocity.

G. K

The Cupola Battery, Pampas, near Amsterdam.

By T. Z. Stuten.

(Tijdschrift van het Koninklijk Instituut van Ingenieurs, 1892–93, p. 9.)

For the defence of Amsterdam against an attack by vessels on the Zuyder Zee a fort was required; and it was decided to locate this on the fairway of Pampas, leading from the passes between the North Sea islands towards the roadstead of the Y. The situation was chosen about a mile and a half from the south coast of the Zuyder Zee, nearly due north of the entrance to the port of Muiden, where, after careful sounding, a bottom was found, consisting of weak clay overlaying sand at a depth of 9 feet 4 inches below mean sea-level.

Surrounding the site of the artificial island to be formed here a channel was dredged, about 42 feet wide and 10 feet deep, to remove the top layers of soft clay and silt; and this channel was immediately filled up again with clean sand to the level of the surrounding sea-bottom. On this sand-bed a layer of fascine mattresses was sunk, and this covered with stone riprap up to mean sea-level, and a width at the top of 6 feet 8 inches. The inside slope of this riprap ring-dam was then covered by a layer of broken brick 2 feet 6 inches thick, and over this again a layer of clay 11 feet thick. Inside of this inclosure a pit was dredged to a depth of 17 feet 4 inches below mean sea-level, and filled in again with pure sand, to serve as a first foundation for the buildings. Through an opening left in the ring-dam the whole enclosed space was then filled in with sand to 8 inches above mean sea-level. While this sand mound was settling, the ring-dam was strengthened so as to form a proper sea-dam with outward slopes of 6 to 1, covered with a pitching of basalt and a core of clay, dredged in the neighbourhood. The spot intended for the heavy concrete

casemates and buildings was then loaded with an additional mass of sand to a height of 31 feet 8 inches above mean sea-level.

Under this weight the bottom layers settled 2 feet 8 inches. As soon as this sand-bed had come to rest, the pile-foundation for the building was commenced, consisting of three thousand nine hundred piles 36 feet 8 inches long, each calculated to carry a weight of 16 tons, and spread over an oval area, the form of the fort. This structure contains a cube of 31,600 yards of concrete and brickwork, and is crowned with two Gruson cupolas, each containing two muzzle-pivoting guns of over 20 tons weight. The cupolas and shields weigh 515 tons and 436 tons each respectively. The cupolas stand over shafts communicating with tunnels below; while the fort is isolated from the surrounding sea-dam by a dry moat, from which light and air is obtained for the casemates, dwelling-rooms, and magazines.

H. S.

Electric-Welded Projectiles. By Hiram Percy Maxim.

(Proceedings of the United States Naval Institute, 1892, p. 251.)

The processes at present in use for producing forged steel projectiles are tedious and difficult. It has been rendered possible by the invention of electric welding to produce a forged steel shell at about the same price as it now costs to manufacture the common cast-iron projectile. This is accomplished in the following manner:—

Hollow steel blooms are cast and from them is rolled out a thick walled tube having the approximate finished dimensions of the body of the shell. This is cut into suitable lengths, and the head and base of the projectile which have been previously formed in suitable dies are welded on. The only machining necessary is turning to gauge on the outside, cutting the groove for the rotating band, and the fuze-thread and seat. When hardened, a thoroughly efficient and cheap wrought-steel shell is produced. It is possible to weld a high carbon steel head on to a body of lower grade, less expensive material. The head-section is hardened uniformly all over; the others are not hardened at all. When they are joined by the electric-welding process, one of the features of which is the limiting of the heat to a short distance on either side of the joint, the shell is placed with a portion of the head in cold water, and the heat from the weld draws the temper gradually towards the point. The hardening of the head alone is a much simpler operation than heating and hardening the whole projectile, and temper-cracks and other defects may be discovered in this portion before it is welded. Shrapnel shell is being made by the same process. A description with illustrations of the welding machinery, as used by the American Projectile Company, Lynn, Massachusetts, follows.

S. W. B.

The National Small-Arms Factory at Liége.

By L. Castermans and F. Melotte.

(Revue Universelle des Mines, vol. xix., 1892, p. 18.)

In 1886, several of the principal gun-making firms in Liége formed a syndicate for the erection of a small-arms factory upon the most improved principles; and upon receiving an order for one hundred and fifty thousand to two hundred thousand Mauser rifles, cal. 6·75 millimetres, from the Belgian Government, a company called the National Military Arms Factory was organized for carrying out the scheme. The factory designed by Mr. Castermans is placed entirely on the ground-level, avoiding the use of upper floors, the largest portion of the machine-tools being contained in a large hall about 345 feet long and 245 feet broad, placed at some distance from the forges and the engine and boiler-houses, in order that their working may not be influenced by shocks or dust. The more dangerous shops in which wood-working is carried on are also placed on the outside so as to be readily accessible in case of fire. The site selected, of about 20 acres, is at Herstal, which necessitates the use of pumping machinery to bring feed-water from the lateral Meuse Canal, at a distance of about ½ mile—an inconvenience which is, however, counterbalanced by having skilled workmen close at hand, the locality being in the centre of the gun-trade.

The area of the covered buildings is 22,000 square metres; they were completed in six months, which involved the execution of—

10,000 cubic metres of	excavation,
8,000 ,,	masonry,
700 tons	roof framing,
22,000 square metres	roofing and slating,
14,000 ,,	flooring,
6,000 ,,	glazing.

The great hall is divided into fourteen bays by lines of columns spaced 7½ metres apart, each being of sufficient width to take four rows of machines with a passage between them. The roof-lights are glazed with large sheets of plate-glass, which dispenses with the ordinary heavy iron sashes, besides diminishing the chance of breakage. A proof-house, with a sighting-range of 200 metres, adjoins the factory on one side.

The chief point of interest is, however, to be found in the arrangement of the driving-power and transmissions. For the actual work of the machines, thirteen lines of shafting, varying in their demands for 12 to 30 HP. each, to a total of 200 HP., are required; but in order to obtain the necessary subdivision from a single motor by the ordinary method of driving with leather belts or manilla ropes, about 70 tons of intermediate mechanism, 40 tons of shafting and pulleys, and 30 tons of bearings, would be

necessary. As an alternative, a telodynamic cable for carrying a large portion of the power by a single change was suggested but was considered objectionable, the large driving-pulleys, 14 feet in diameter, and the presence of a rope travelling at very high speed through the shops, being likely to cause inconvenience.

It was ultimately decided, on the proposition of the Compagnie Internationale de l'Électricité, to drive each of the separate lines of shafting in the shops by an electromotor receiving the current from a dynamo connected with the main engine whose armature replaces the fly-wheel of the latter. In this manner a current of 2,440 amperes at 125 volts is produced by an armature of very large size, moving at the low speed of 66 revolutions per minute—a combination which has not hitherto been attempted, at any rate upon the same scale. The second memoir by Mr. Melotte, p. 28, gives the details of the electrical work.

The power required being 200 HP., the motors supplied and their guaranteed efficiencies are :—

HP.	HP.				HP.	HP.		Per cent.
9 of 12 =	108,	require	9	motors of	16 =	144,	efficiency	87
2 ,, 16 =	32,	,,	2	,,	21 =	42,	,,	87
2 ,, 30 =	60,	,,	2	,,	37 =	74,	,,	89
	200					260		

which requires $165 \cdot 5 + 48 \cdot 3 + 83 \cdot 1 = 296 \cdot 9$, or, allowing 2 per cent. for loss in the conductors, 303 HP. at the terminals of the dynamo. The efficiency of the latter being guaranteed at 90 per cent. of that of the engine, the available work demanded from the fly-wheel shaft is $333 \cdot 6$ HP., corresponding to a transmission of $77 \cdot 2$ per cent.

The horizontal compound condensing engine of 500 HP. is made by Mr. Van den Kerkhove, who guaranteed the internal resistance not to exceed 8 per cent., or 40 HP., but it has been found to be something less than 6 per cent., allowing for which the final result comes out as $72 \cdot 5$ per cent. of the indicated HP. available at the driving-pulleys of the motor dynamos.

The main dynamo is of the Gramme type of construction, that system of winding being called for by the large dimensions of the armature. Further particulars of the dynamo will be found in a previous abstract.[1]

About 110 HP. is taken off the main current for the electric lighting, which includes one hundred and sixteen arc-lights of 10 amperes, arranged two by two in series, and two hundred 16-candle incandescent lights. The latter are supplied from a ring with twenty-four feeders, which are not covered except in the tunnel between the engine-room and the distributing-board. The drop in the current is 7 volts when the whole of the lamps are lighted.

The motors distributed through the works are all of the same kind, with a double magnetic circuit and Gramme armatures.

[1] *Ante*, p. 476.

The magnet-cores are cylinders of wrought-iron, placed upright with cast-iron pole-pieces, which are fitted to the framing and bored out at the same time as the shaft-bearings, in order to have the armature perfectly centered. The armature core is formed of disks of sheet-iron, carried upon a series of arms parallel to the shaft attached to a boss cast in bronze. The winding has only a single outer layer of wire. The ends of the commutator plates are contained in a hollow cone of cast-iron, which is secured by a conical ring, the whole forming a perfectly compact mass which cannot be distorted even by the blow of a hammer. The brushes are made of a special kind of carbon, which gives no trouble even under considerable variations in load, so that the electrician in charge has only to attend to the starting and stopping, the greater part of his time being occupied with clearing and replacing the carbons of the arc-lights, which, as before stated, are one hundred and sixteen in number, distributed over an area of about 11 acres.

The number and distribution of the motors in use is as follows :

Position.	HP.	Number.	Guaranteed Efficiency.
			Per cent.
Great Hall	16	9	87
Wood-working shop . . .	21	1	87
Forges	37	2	89
Breech-action shop . . .	16	1	87
Polishing-shop	16	1	84
Pumps	10	1	85
Ventilator	3	1	80
Cartridge-shop	21	1	..

The average efficiency of the motors is 87 per cent., which, multiplied by 98 per cent. for that of the conductors and 90 per cent. for the principal dynamo, gives 76·6 per cent. as the efficiency of the transmission, that is, the relation between the steam-power and that delivered to the shop shafts. The total weight of copper in the distributing circuit is 5·4 tons.

In the third section of the Paper, the Author discusses the comparative value of mechanical and electrical transmission working under full and reduced loads. In the latter method the resistances producing losses are made up of those of the magnetic core which are substantially constant, and those of the armature-wire and the armature-bearings and conductors which, according to Joule's law, are proportional to the resistance of the conductors and to the square of the intensity of the current; while in the former the losses in transmission are constant whatever may be the proportion of power utilized, so that this method becomes very disadvantageous when the power is not fully employed. This is shown in the following Table where the losses are supposed to be

the same on both systems under full load, which is putting it rather too favourably for the mechanical system.

ELECTRIC TRANSMISSION.

Power charged	1,000	750	500	333	250	200
Fixed losses	50	50	50	50	50	50
Variable losses	50	27	11	4·5	2·2	1·2
Disposable energy of dynamo	900	673	439	278·5	197·8	148·8
Efficiency, per cent.. . .	90	89·7	87·8	83·5	79·1	74·4
Loss in conductors, variable	18	10	4	1·7	0·8	0·5
Disposable at motor. . .	882	663	435	276·8	197	148·3
Fixed losses, 6 per cent. .	53	53	53	53	53	53·0
Variable losses, 4 per cent..	35	20	8·5	3·4	1·7	1·0
Disposable energy . . .	794	590	373·5	220·4	142·3	94·5
Final efficiency, per cent. .	79·4	78·7	74·7	66·2	57·0	47·2

MECHANICAL TRANSMISSION.

Power charged	1,000	750	500	333	250	200
Fixed losses	206	206	206	206	206	206
Useful work	794	544	294	127	44	..
Final efficiency, per cent. .	79·4	72·5	58·8	38·1	17·6	..

From which it appears that with the motor at half-power and below, the loss in transmission is very much larger by mechanical than by electrical means.

A fourth section of the Paper describes a series of determinations of the average power required by different groups of machines and the loss on the intermediate transmissions. This was done by interposing in the circuit of a motor driving a principal line of shafting a registering ampere meter, giving a curve of which the abscissæ are proportional to the time and the ordinates to the intensity of the current. As the latter bears a certain ratio to the energy absorbed by the motor, it is easy to compute, from the curve, the work done at any particular moment when the voltage and proportional effect are known, and the measuring apparatus used in this way becomes a most perfect dynamometer. The method has been applied to determining (1) the work absorbed by different machine-tools, (2) the requirements of the different shops under ordinary working conditions, and (3) the coefficient of friction of the different lines of shafting. Several of the diagrams are given in the accompanying plates which show the demand on the engines to be extremely irregular and to vary very rapidly; but as a rule not more than 50 to 60 per cent. of the total power is required with the shop in full work. In the first bay of the great hall containing the most exact tools employed on the production of cutters and drills, when very actively employed, the average power taken was 7·3 HP. during several hours observation with a maximum of 11 HP. for a few moments when several

heavy machines were put in gear simultaneously. During the remainder of the time the power varied from $8\frac{1}{2}$ to 6 HP. and sometimes fell to 5 HP. When all the machines were thrown into gear with their cutting-tools lifted the meter registered 11 HP., and the shafting alone running empty 4 HP. or 55 per cent. of the 7·3 HP. required under normal working conditions.

In a similar experiment made at the Royal Arsenal at Liége, a group of machines required 6·2 HP. when doing no work, which was raised to 6·9 HP. when the cutting-tools were made to bite. When all the machines were thrown off 4·2 HP. was registered, showing that 2 HP. was required by the tools (shaping-machines and lathes) when running light, and only 0·7 HP. more when doing work. The proportion of the latter is 26 per cent. of the work supplied to the machines as 1·25 per cent. of that of the powerful shaft. These results indicate very clearly how small a fraction of the power supplied to machine-shops is actually utilized and the profits to be looked for in improving methods of transmission. The advantages of electrical transmission are set forth at length in the conclusion of the Paper.

H. B.

Revolving Dome of Meudon Observatory.

(Le Génie Civil, vol. xxi., 1892, p. 389.)

This dome has a diameter of 62 feet 4 inches, and was constructed by the Société Cail. The framework is carried by two principal arched beams, parallel, at a distance apart of 9 feet 2 inches, thus leaving an opening of that width for the telescope. On these rest twenty-six quadrant-shaped joists united by three horizontal circular joists. The dome is covered by steel-sheeting outside with an inner roof of wood, and the opening can be closed by shutters worked from the floor. The dome turns on a live ring of twelve rollers weighing $1\frac{1}{2}$ ton each, and is maintained in its true position by horizontal rollers which allow a play of 2 inches.

The observers, &c., are carried by a platform of an area of 172 square feet, attached to and turning with the dome, and having also an independent motion to follow the movements of the eye-piece of the telescope in the vertical plane.

The various motions are actuated by electrical machinery controlled from the platform above mentioned. The current is generated by a 6-HP. gas-engine driving a dynamo of 4,000 watts. This furnishes current to two motor dynamos, one of which drives by worm-gear the drum over which passes an endless rope encircling the lower edge of the dome, and the other, moving with the platform, winds or unwinds (also by means of worm-gear) chains by which the platform is suspended and which carry

counterweights. The circular ascent and descent of the platform is obtained by guides, between which wheels attached to the platform are made to travel. The total weight of the construction is 160 tons, of which the movable part forms 120.

C. F. F.

A New Process for the Manufacture of Potash.

By D. Sidersky.

(Le Génie Civil, vol. xxi., 1892, p. 410.)

The production of potash from the Stassfurt salts, which consist of variable compounds of sulphates and chlorides of potash, soda, and magnesia, has hitherto been effected by the Leblanc process, a method which is not only expensive, but gives a large amount of waste products, while the finished article is not easily obtained in a pure state; so that these minerals are almost entirely sold for agricultural purposes. In the new method described by the Author, and patented by the Buckau Chemical Company, the whole of the constituents are utilized with the production of potash, soda, calcined magnesia, crystalline sulphate of lime, hydrochloric acid, and sulphuric acid.

The material best suited for the process is the mineral kainite, whose average composition is—

	Per cent.
Magnesium sulphate	16 to 18
Potassium „	22 „ 24
Sodium chloride	30 „ 40

This is first converted into sulphates by treatment with sulphuric acid, the hydrochloric acid being condensed, as in the Leblanc process. The magnesium sulphate is next decomposed by the addition of lime, which produces calcium sulphate and magnesia, both of which are insoluble. This operation is effected by adding the necessary quantity of concentrated milk of lime to the boiling solution of kainite sulphates of a density of about 20° Baumé. At first the lime dissolves in the hot solution; but when left at rest for some days after slow cooling, the calcium sulphate separates as a heavy crystalline powder covered with a lighter deposit of magnesia. These, after removal of the saline solution, are washed and separated by decantation, and finally collected in the filter-press.

The solution of potassium and sodium sulphates is next treated with barium sulphide, giving insoluble barium sulphate and solutions of the alkaline sulphides, which, after filtration, are boiled down to a strength of 20° Baumé, and subjected to the action of pure concentrated carbonic acid gas obtained from the decomposition of alkaline bicarbonates. This decomposes the sulphides, producing sulphuretted hydrogen, which is burned and converted into sul-

phuric acid and bicarbonates of sodium and potassium. The former salt, being almost insoluble in the cold solution, is separated by filtration, and the potassium salt is obtained by boiling down the filtered liquid. Lastly, the bicarbonates are transformed by calcination into neutral carbonates, the carbonic acid gas driven off being employed in the decomposition of the alkaline sulphides. This is said to be the first industrial application of pure carbonic acid, and to be essential to the success of the operation, which cannot be carried out with limekiln gases, on account of the presence of free oxygen in the latter, whereby a certain proportion of the sulphides are invariably changed into sulphates.

The order of operations given above may be varied by separating the magnesia with lime before the conversion into sulphates. The mixed sulphates may also be converted into sulphides by calcination with coal, which completely decomposes the magnesian sulphate, and converts the alkaline sulphates into sulphides. The product when lixiviated in Shank's apparatus, gives a precipitate of magnesia and alkaline sulphide liquors for the carbonic acid treatment. The conversion of potassium and sodium sulphates into sulphides by carbon alone has not been found to be practicable, owing to their ready fusibility and corrosive action upon the furnace-bottom when melted. The presence of magnesium sulphate, however, alters the conditions, as the mass becomes fritted with an infusible substance, caustic magnesia, and the conversion takes place at a temperature below that necessary to develop the corrosive action of the material.

H. B.

Recent Apparatus for Cremation.

By Dr. T. Weyl, of Berlin.

(Gesundheits-Ingenieur, 1892, p. 377.)

After a brief historical account of the practice in all past ages of cremating the dead, introduced by the Arian race, the Author traces the modern revival of the idea to the close of the eighteenth century, though from that time until the first cremation in Europe, which took place at Milan on the 27th of January, 1876, a period of nearly eighty years elapsed. Since then the practice has attained in Italy such a great extension that there were in 1890 no less than twenty-seven crematoriums in operation in that country alone. The interest in this matter was first aroused in Germany, when on the death of Jacob Grimm it was proposed to dispose of his remains in a thoroughly Germanic way—by fire. It was necessary, however, for Mr. F. Siemens to remodel the system of combustion before the small city of Gotha adopted the principle of cremation in 1878. More than twelve years elapsed before Hamburg followed suit in 1891; the same year saw the plan in

operation in Heidelberg, and crematoriums are now erected in Offenbach and Berlin. The number of cremations in Paris reaches an annual total of four hundred, and this system of disposing of the dead is partially in use in Switzerland, Denmark, Sweden, and the United States. It is shown that the chief obstacles to the spread of cremation are the religious objections to the practice, and a fear of encouraging crime by the impossibility of any subsequent chemical or anatomical investigation. The advantages of the plan from the point of view of economy and hygiene are discussed, and the Author insists upon the necessity of this plan of disposing of the dead in consequence of the growth of large cities. He classifies the existing establishments under two heads: those without regenerative furnaces and those which adopt this plan. To the former class belong the crematoriums at Milan on the system of Gorini, which is explained by reference to a diagram, and that of Venini, which is simply a modification of the process of Gorini, and is in use in Italy and Denmark, as also in North and South America. In the latter class are included the crematorium at Gotha, constructed by F. Siemens, in which during the twenty-one years ending November, 1891, no less than nine hundred and seventy-six bodies had been disposed of. The process here lasts two hours and a half, and the cost is about 80 marks (£4). The system of Bourry in Zurich is a modified form of the Siemens principle. In the same way the furnace of Toisoul and Fradet at Père-la-chaise, Paris, of which an illustration is given, that of Müller and Fichet at the same crematorium, the process of Klingenstierna at Stockholm and Gothenburg, and that of Schneider, are founded on the regenerative furnace of Siemens. A plan and section is given of the arrangement of the Hamburg crematorium with Schneider's apparatus. The furnace of Guichard, of which illustrated details are furnished, differs from those already described by the use of coal-gas and compressed air; it has, therefore, no gas-producer furnace. In an experimental trial of this apparatus at Paris in 1889, the process lasted forty-six minutes and involved the use of 190 cubic metres of gas and 500 cubic metres of compressed air. A Table is appended, giving the cost of cremation on each system, together with the time employed both in the antecedent heating and also in the cremation itself.

G. R. R.

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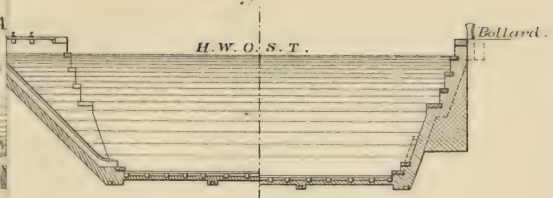
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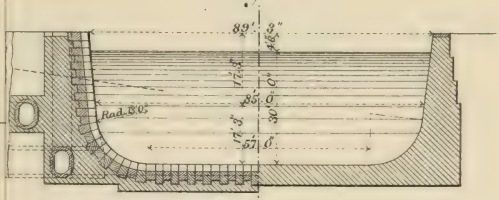

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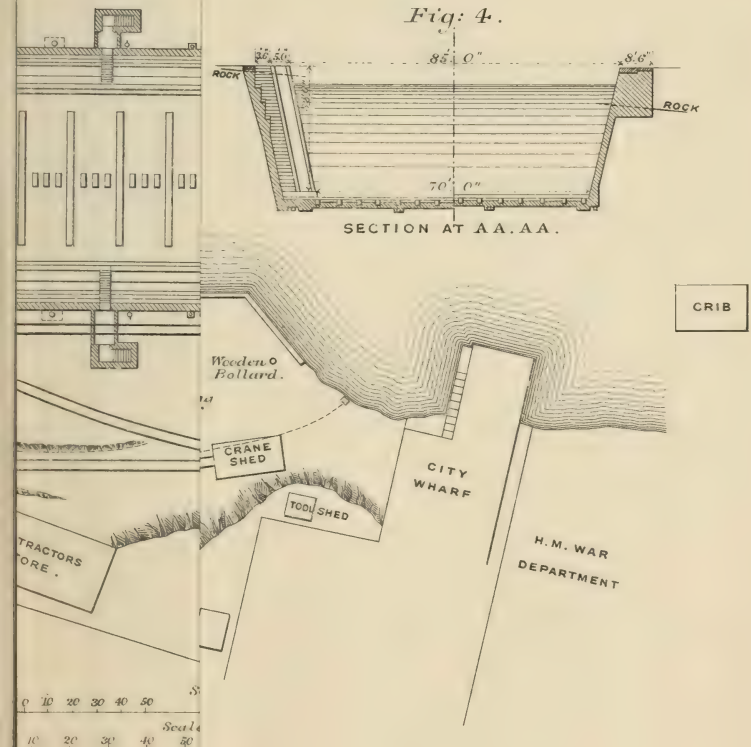
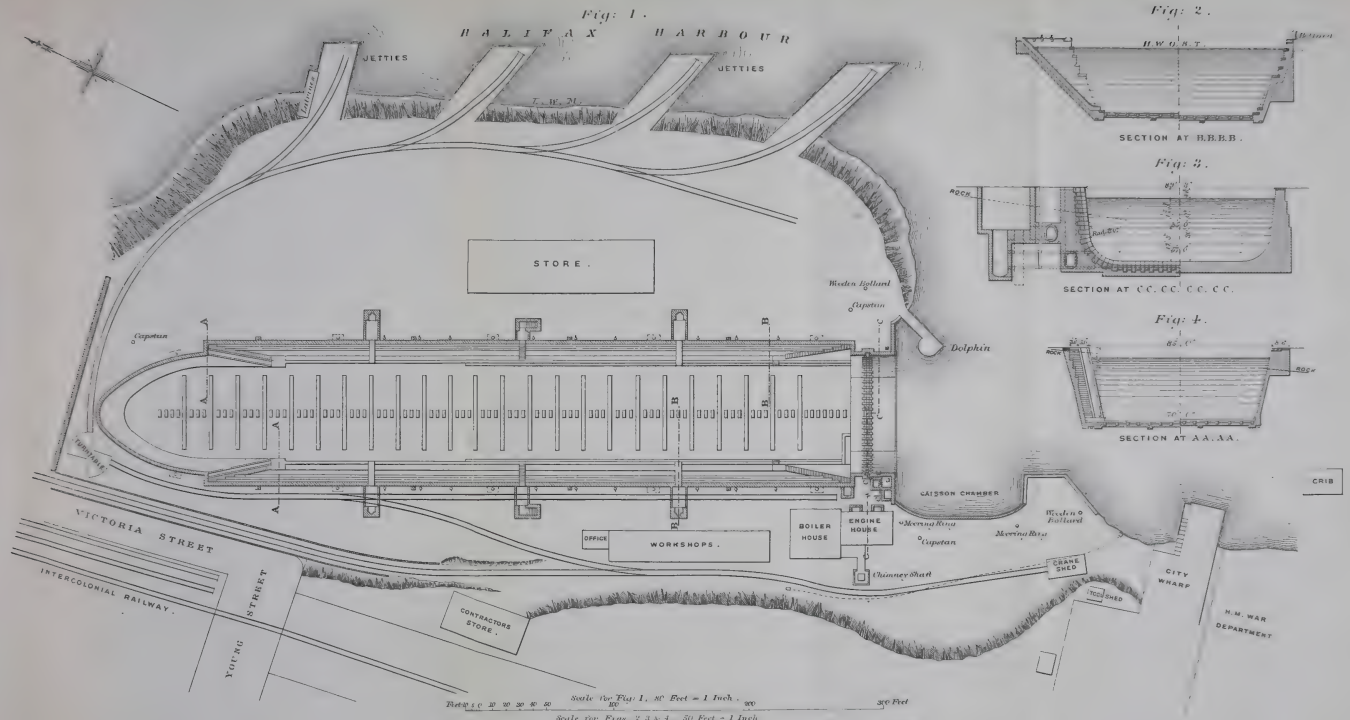
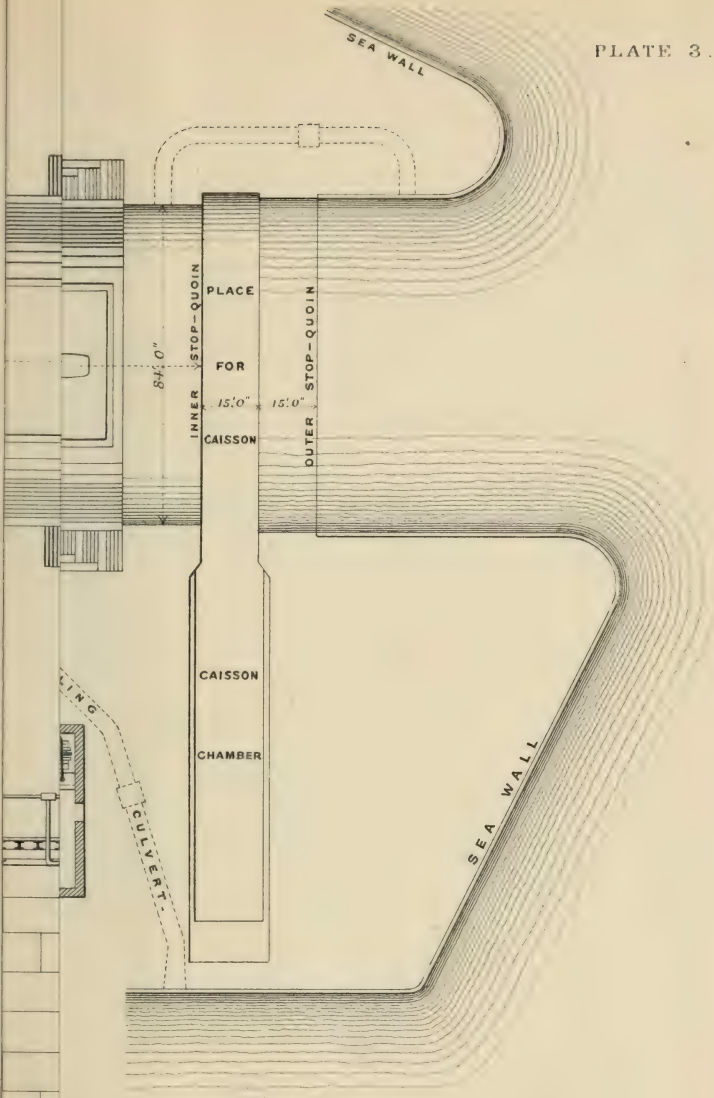


THOS KELL & SON LITH. 47 KING ST COVENT GARDEN.

HALIFAX GRAVING DOCK, N.S.





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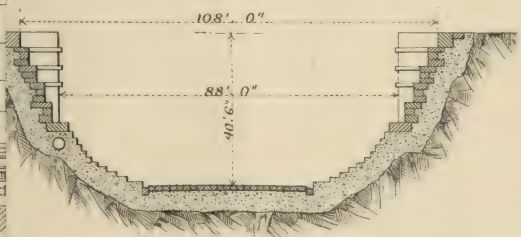


SECTION OF GRAVING DOCK.

Scale 2 — 50 Feet = 1 Inch.

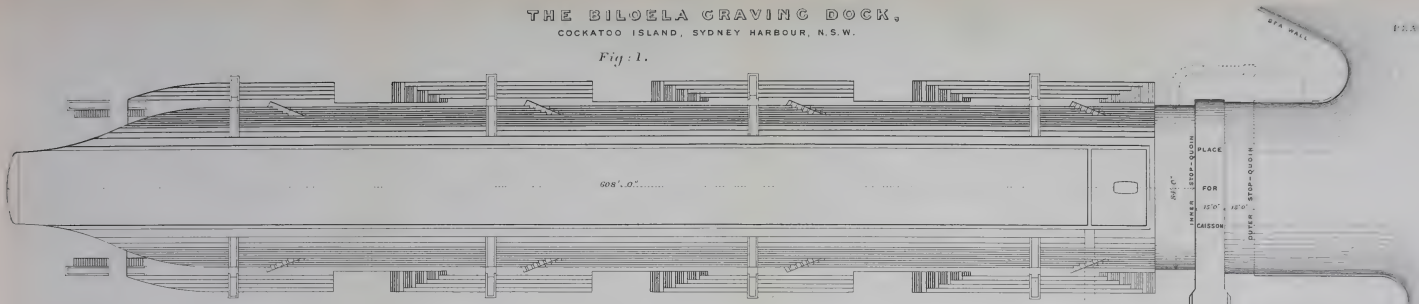
50 100 150 Feet.

THOS KELL & SON, LITH. 40 KING ST COVENT GARDEN

THE BILOELA GRAVING DOCK,

COCKATOO ISLAND, SYDNEY HARBOUR, N.S.W.

Fig: 1.



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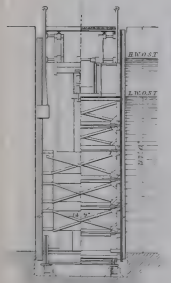
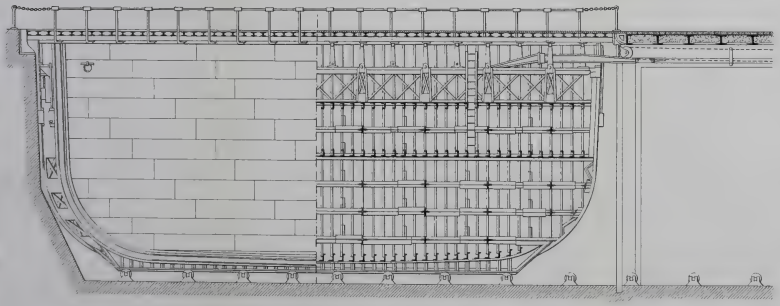


END ELEVATION. CROSS SECTION.

Fig: 4.



ELEVATION. LONGITUDINAL SECTION.

CAISSON.

Scale for Figs. 3 & 4 - 16 Feet = 1 Inch.

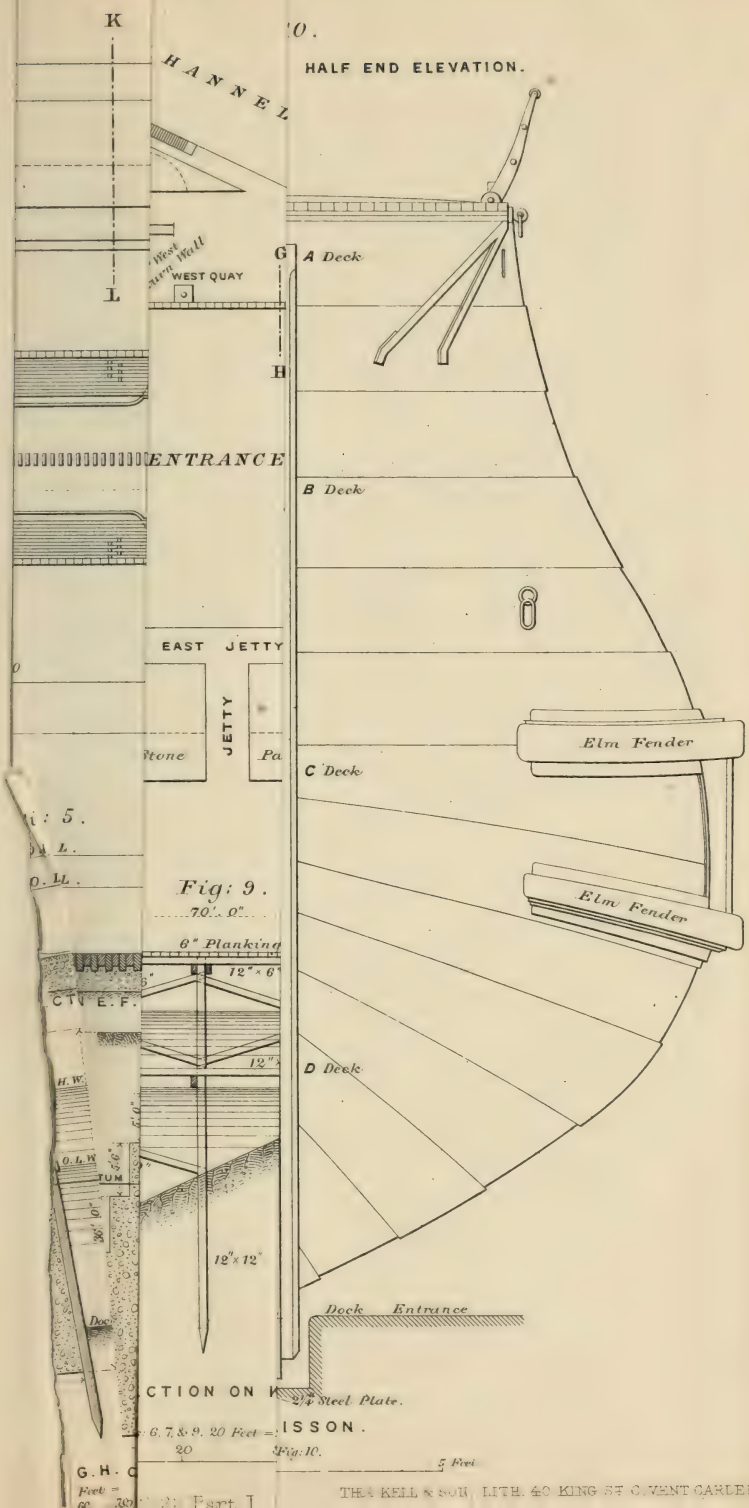
Feet 0 8 16 32 40 50 Feet.

Fig: 2.

SECTION OF GRAVING DOCK.

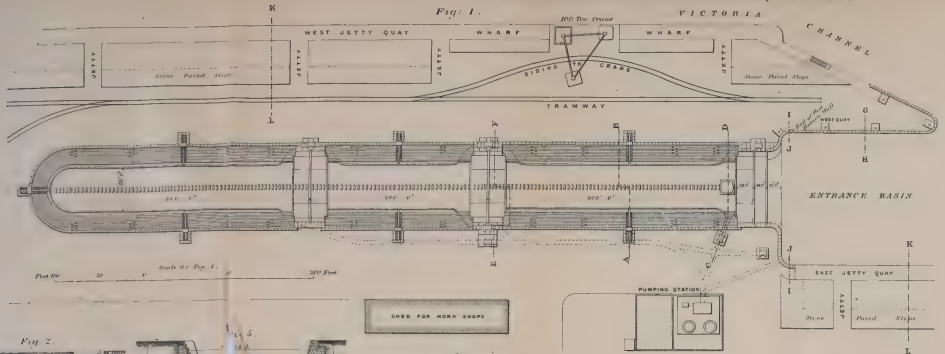
Scale for Figs 1 & 2 - 50 Feet = 1 Inch.

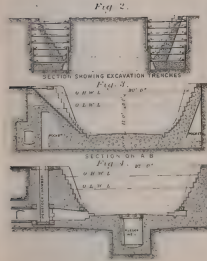
Feet 70 40 30 20 10 0 30 100 150 Feet

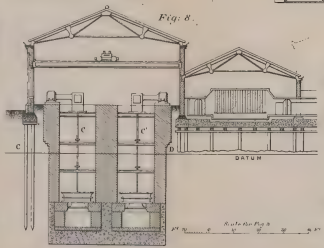


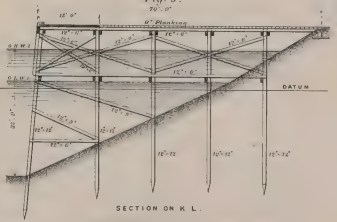
THOS KELL & SON, LITH. 40 KING ST. COVENT GARDEN.

THE ALEXANDRA GRAVING DOCK, BELFAST.









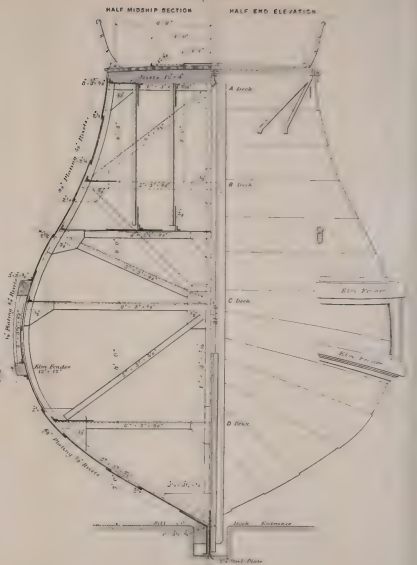


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Fig: 4.

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K

Fig: 5.

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14.0"

CLAY

SAND

SAND

GRAVEL

C

TION ON D.D.

Fig: 6.

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CLAY

SAND

SAND

GRAVEL

PLAN.

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e for Figs 1, 2, 3, 4, 5, 6.

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30 40 50 10 Feet.

Fig: 8.

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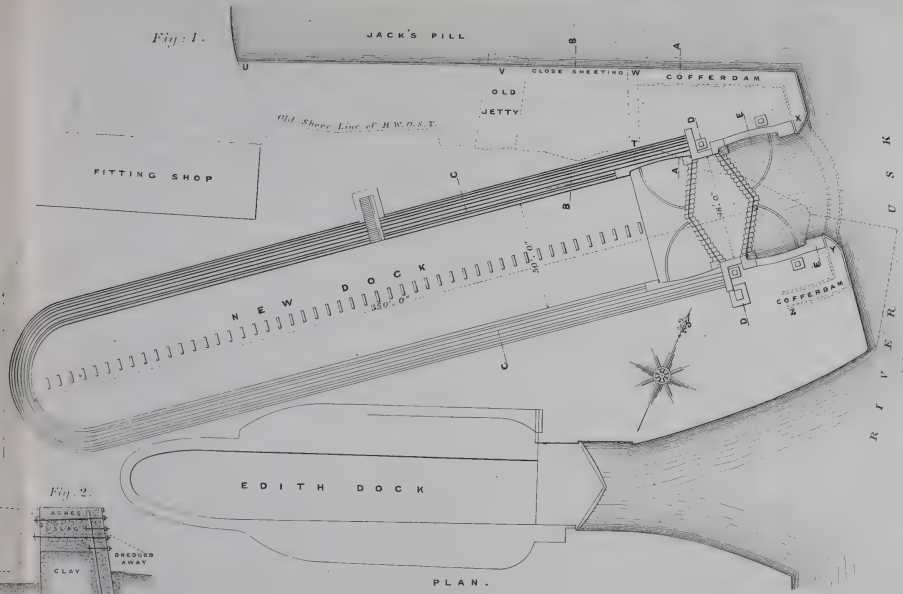
DOCK GATES.
VERTICAL SECTION.

CONCRETE GRAVING DOCK AT NEWPORT, MON.



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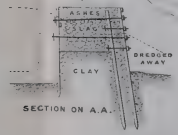

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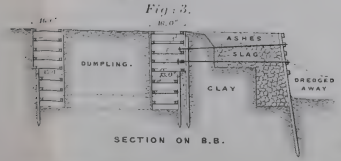

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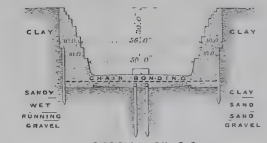

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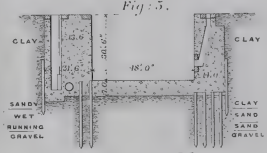

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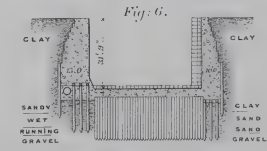

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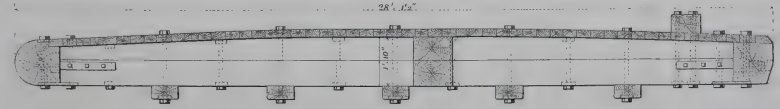
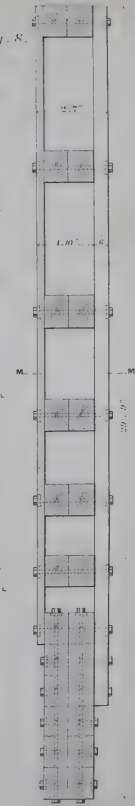


Fig: 7.

Scale for Figs. 1, 2, 3, 4, 5, 6 — 50 Feet = 1 Inch.

Scale for Figs. 7 & 8. 4 Feet = 1 Inch.

Fig: 8.



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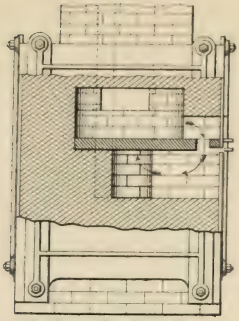
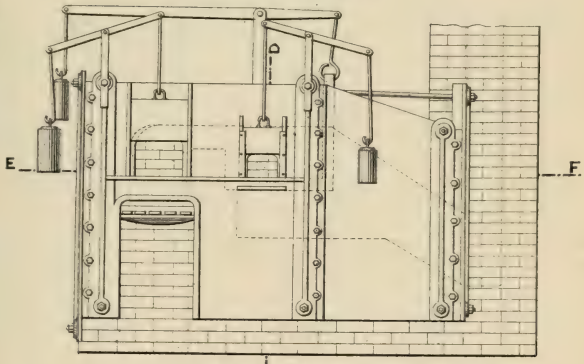
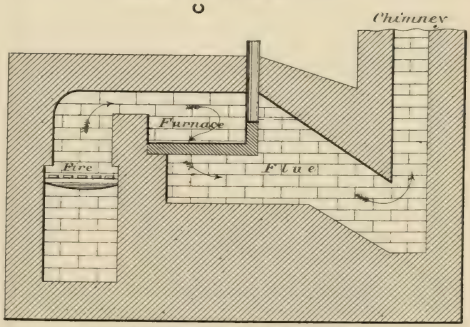
Figs: 7.



PART SECTION ON C.D.



FRONT VIEW.



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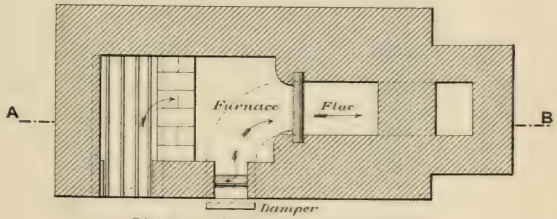


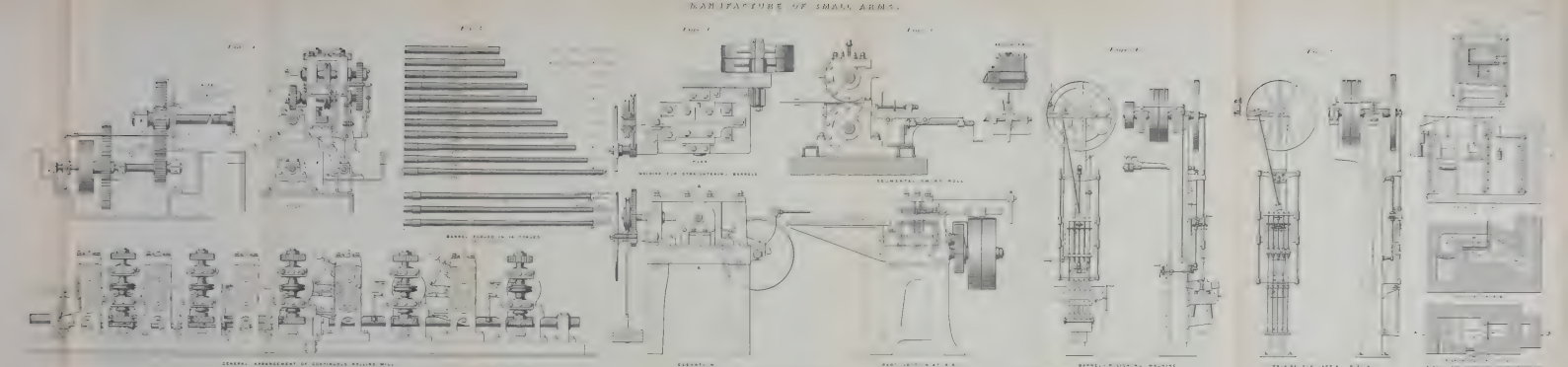
PLAN ON SECTION LINE E.F.

FURNACE FOR HARDENING SWORD-BAYONETS.

Scale ½ Inch = 1 Feet. For Figs. 7.

Inches 12 6 0 1 2 3 4 5 6 Feet.

THE KELL & ALN LITH & KING ST COVENT GARDEN.



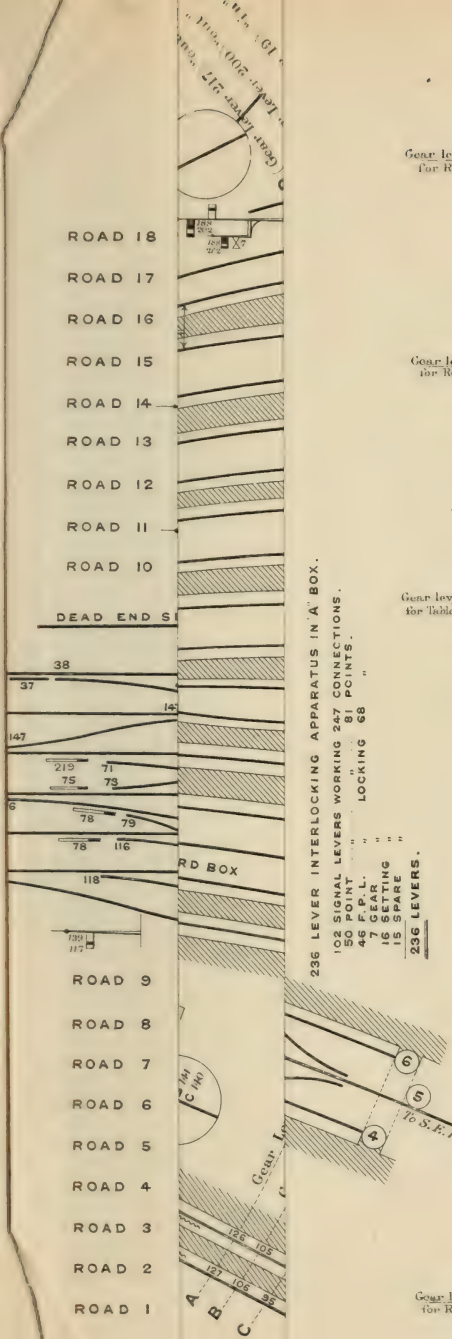


DIAGRAM OF LEVERS.

236 LEVER INTERLOCKING APPARATUS IN 'A' BOX.

102 SIGNAL LEVERS WORKING 247 CONNECTIONS.
50 POINT " " 81 POINTS.
46 F.P.L. " LOCKING 68 "
7 GEAR
16 SETTING
15 SPARE
236 LEVERS.

Gear lever 217 for Road D.

Gear lever 200 for Road E.

Gear lever 180 for Table Road.

Gear lever 128 for Road A.

Gear lever 19 for Road F.

Gear lever 96 for Road C.

Gear lever 197 for Road B.

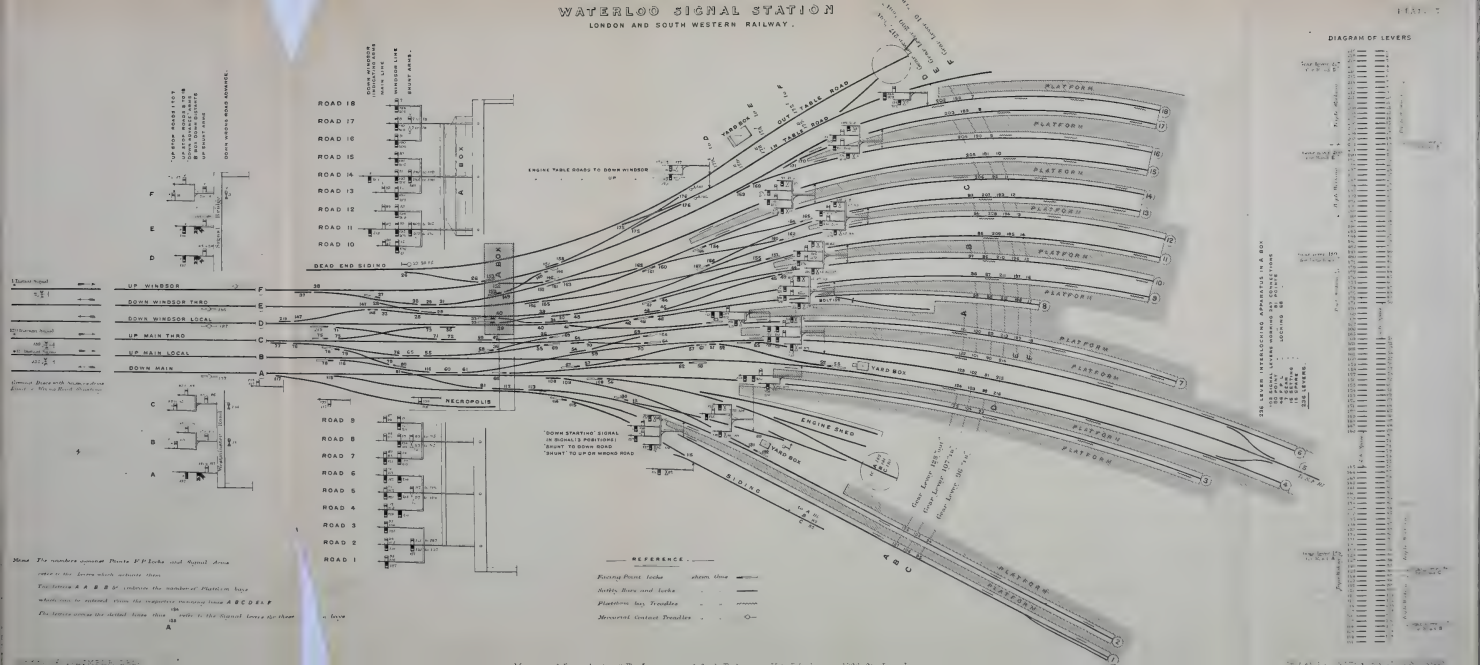
Triple Working

2'6" Space

THOS KELL & SON LITH 40 KING ST COVENT GARDEN

WATERLOO SIGNAL STATION

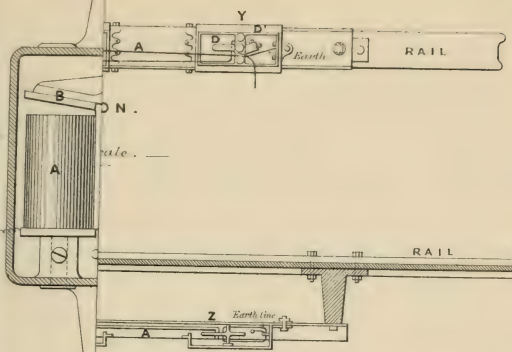
LONDON AND SOUTH WESTERN RAILWAY.



WA

F

14.



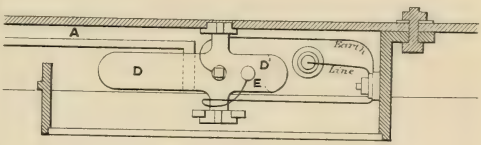
ON.

ale. —

DERCURIAL TREADLE.

ELECTRIC SE

14.



A

NOTE

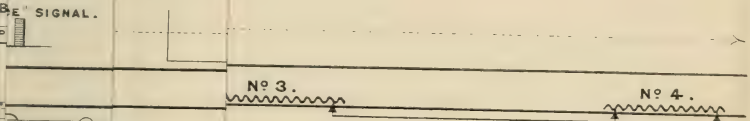
DETAIL AT Z.

ze. —

EVERS & "AD

E" SIGNAL.

P



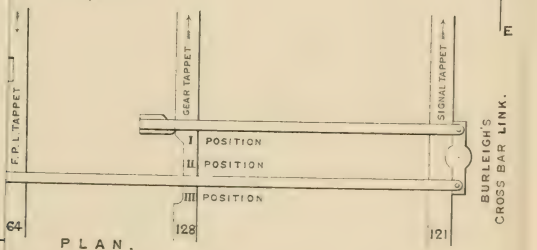
TREADLE

CIRCUIT BY TRA

FORM "IN" SIGNA

E

Fig: 1.



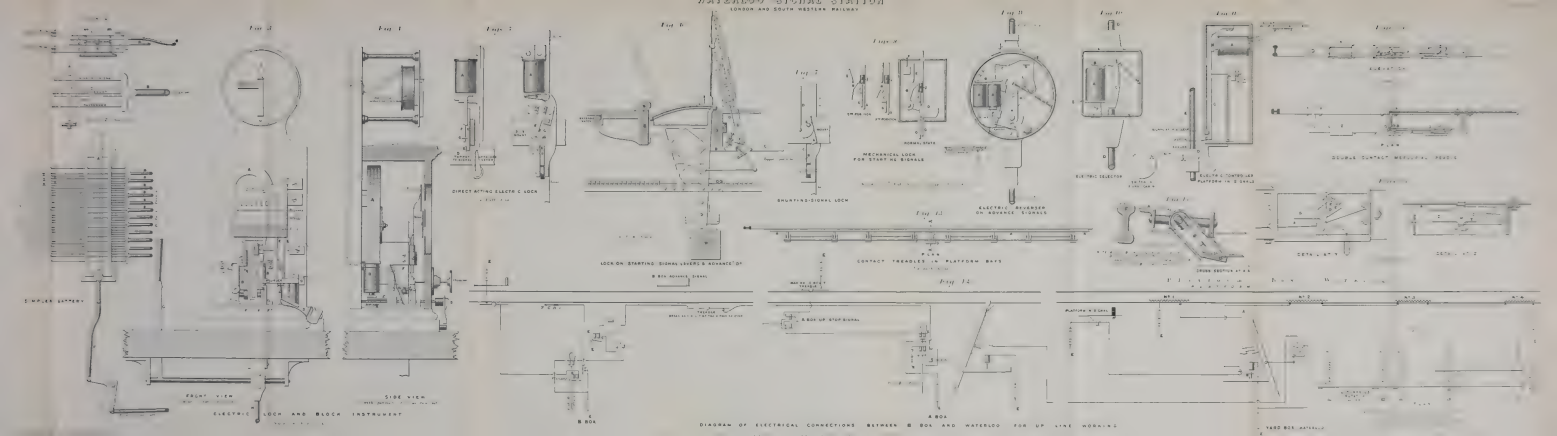
PLAN.

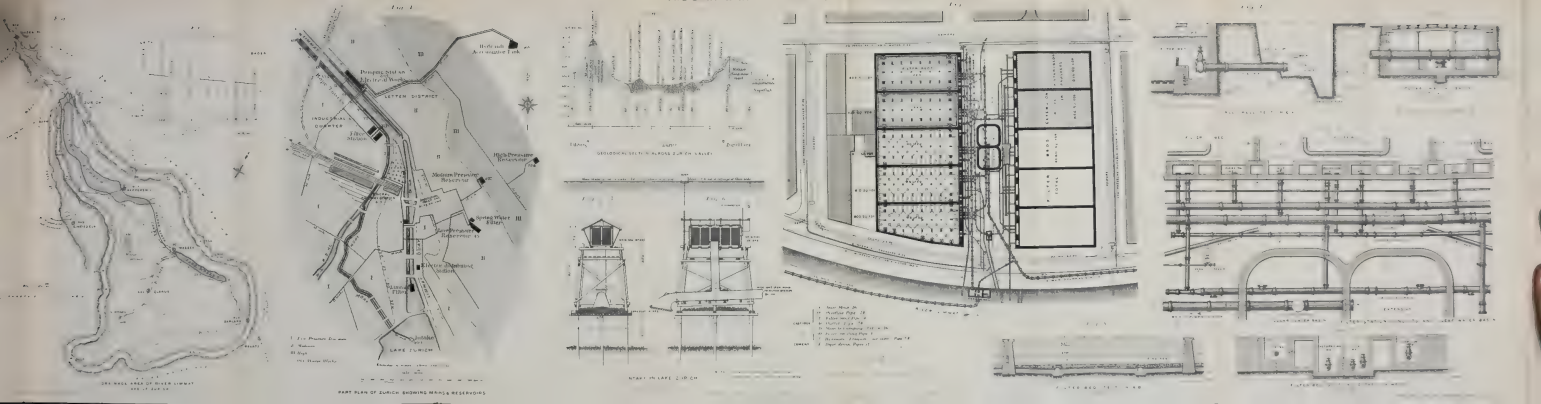
Gs. G3. G2. release 121 when 128 1st position. F.P. lock G2. to be broken G1 or G3. no reversing lever in 128 is in the 2nd or 3rd position.

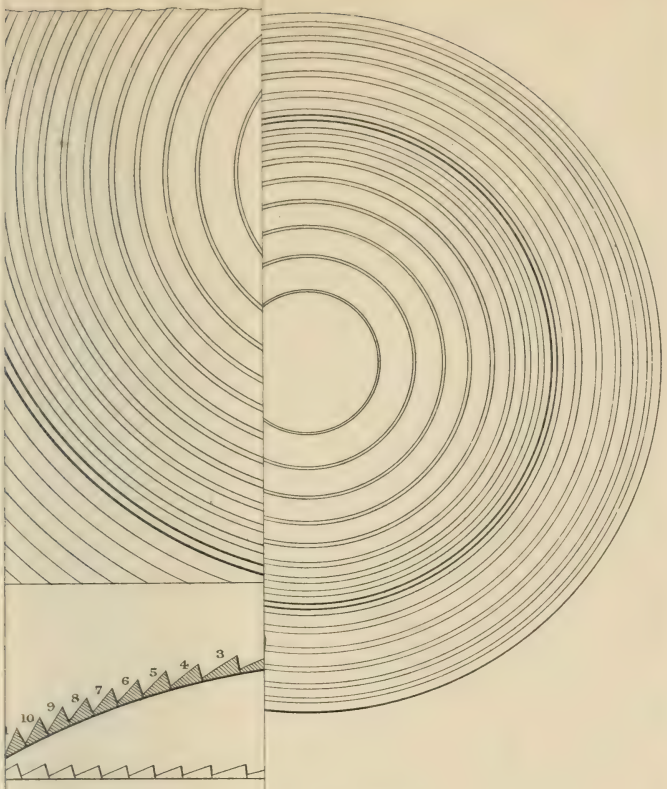
DIAG WORKI

f Proceedu

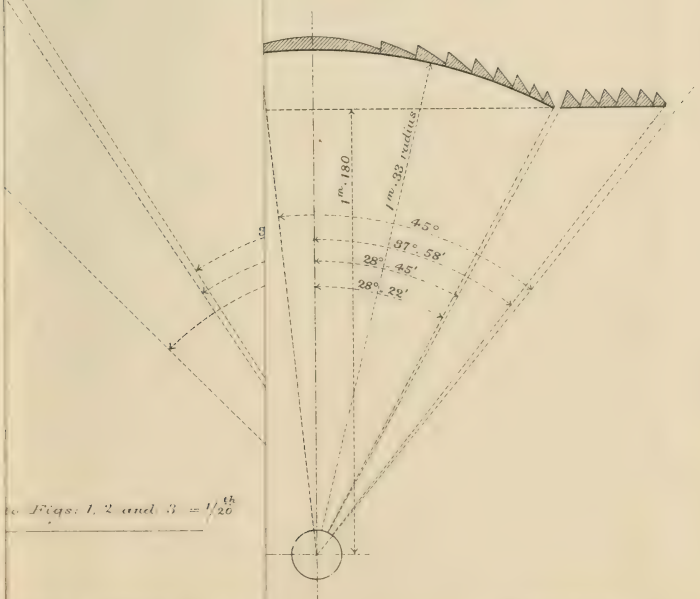
THOS KELL & SON 11 PH. 40 KING ST COVENT GARDEN.


WATERLOO STATION
LONDON AND SOUTH WESTERN RAILWAY
SIMPLEX SWITCH
ELECTRIC LOCK AND BLOCK INSTRUMENT
FRONT VIEW
SIDE VIEW
DIRECT ATTAC ELECTR C LOCK
LOCK ON STARTING SIGNAL LEVERS & ADVANCE DO
B BOX ADVANCE SIGNAL
SHUNTING SIGNAL LOCK
MECHANICAL LOCK FOR START NG SIGNALS
NORMAL STATE
ELECTRIC REVERSER ON ADVANCE SIGNALS
CONTACT TREADLES IN PLATFORM BAYS
B BOX UP STOP SIGNAL
B BOX
A BOX
ELECTRIC SELECTOR
ELECTRIC CONTROLLAY PLATFORM OR SIGNALS
DOUBLE CONTACT MERCURIAL PEDDLE
DIAGRAM OF ELECTRICAL CONNECTIONS BETWEEN B BOX AND WATERLOO FOR UP LINE WORKING
YARD BOX



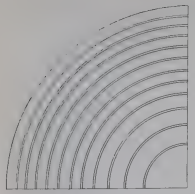


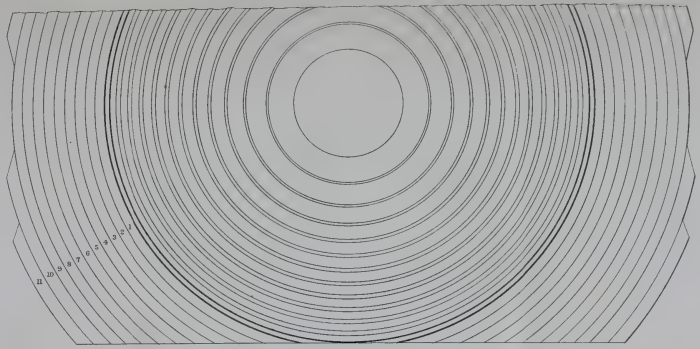
Figs: 3.

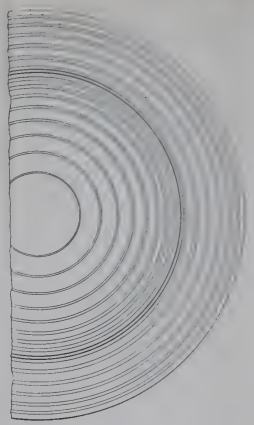


Figs: 1, 2 and 3 = 1/20th

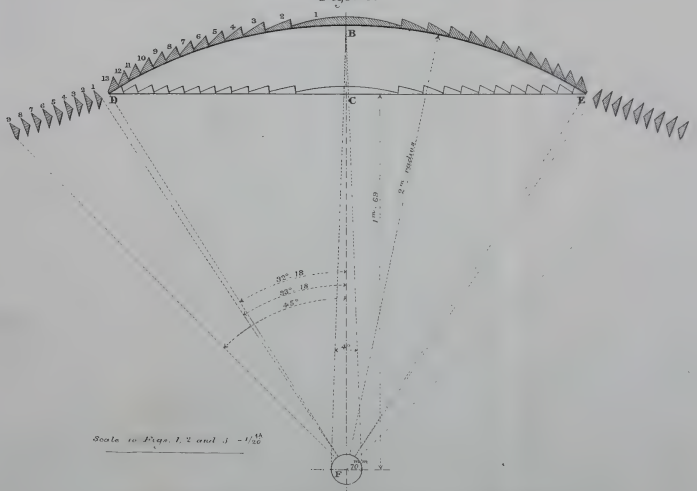
THOS KELL & SON, LITH.





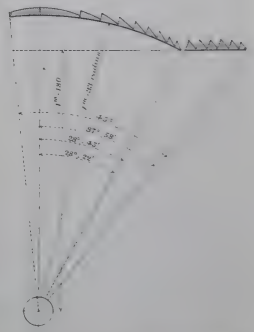


Figs: 2.



Figs: 1.

Figs: 3.



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